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Contents

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9070-1, Session 1

Digital night vision: an IR CMOS solution to 1 mLux imaging

Martin U. Pralle, James E. Carey III, Homayoon Haddad, SiOnyx Inc. (United States)

SiOnyx has demonstrated 1 mLux imaging at 60 FPS on a highly scalable 1.3 Megapixel CMOS image sensor. This performance is enabled by the combination of enhanced quantum efficiency in the near infrared region of the spectrum together with state of the art low noise image sensor design. Quantum efficiency enhancements are achieved through SiOnyx's proprietary ultrafast laser semiconductor processing technology that greatly enhances the absorption of light within the thin pixel layer. The spectral sensitivity ranges from 400 to 1200nm enable the capture of both visible and nightglow photons for imaging from daytime through twilight and into nighttime conditions. This technology demonstrates 10 fold improvements in infrared sensitivity over incumbent imaging technology while maintaining complete compatibility with standard CMOS image sensor process flows. Applications include surveillance, nightvision, and 1064nm laser see spot. Imaging performance metrics will be discussed.

Demonstrated performance characteristics:

Pixel size : 5.6 & 10 um

Array size: 720P/1.3Mpix

Frame rate: 60 Hz

Read noise: 2 ele/pixel

Spectral sensitivity: 400 to 1200 nm (with 10x QE at 1064nm)

Daytime imaging: color (Bayer pattern)

Nighttime imaging: moonless starlight conditions

1064nm laser imaging: below 10 uJ in room light conditions

9070-2, Session 1

A monolithic 640x512 CMOS imager with high-NIR sensitivity

Stefan C. Lauxtermann, Sensor Creations, Inc. (United States); John Fisher, Brandywine Photonics, LLC (United States); Michael H. MacDougal, Attollo Engineering, LLC (United States)

CMOS image sensors have become the workhorse technology in consumer cameras operating in the visible domain. However, remote sensing, biomedical and machine vision applications requiring high sensitivity outside the 400nm and 650nm wavelength range can usually not be served by these mainstream silicon sensors. The choice until now has been fully depleted (FD) CCDs or hybrid FPAs. FD CCDs and silicon hybrid FPAs, built upon a photocharge collection region up to 100 times thicker than the region in commercial CMOS parts, have high quantum efficiency up to 1100nm wavelength. But these traditional FD devices suffer from all or some of the following inherent drawbacks: limited data bandwidth, high design and manufacturing cost, poor pixel scaling, high readout noise, and obsolescence.

To solve this problem, we have developed a monolithic, fully depleted backside illuminated imager with 15 micron pixel pitch and VGA resolution on high resistivity silicon with thicknesses of 50um, 100um and 200um, respectively. The imager is highly programmable and supports frame rates between 30 – 1000Hz through 1, 2, 4 or 8 analog output ports. A high efficiency snapshot shutter provides exposure time control from 200nsec – 30 msec at a readout noise < 10e-. With the built in 2x2 binning function, the signal to noise ratio can be improved by nearly a factor of 4, and a maximum frame rate of 4000Hz becomes possible at a resolution of 320x256.

Latest results from packaged and unpackaged image sensors, including read noise, dark noise, and quantum efficiency, are presented here.

9070-3, Session 1

3D numerical simulation of planar P+n heterojunction In0.53Ga0.47As photodiodes in dense arrays, part I: Dark current dependence on device geometry

Adam R. Wichman, Boston Univ. (United States); Roger E. DeWames, Corbin Co. (United States); Enrico Bellotti, Boston Univ. (United States)

In0.53Ga0.47As on InP P+ n photodiodes are a preferred technology for imaging the visible and short wave infrared in 600 to 1700 nm. Applications sensitive to high detectivity, camera size, weight, and power reduction require photon shot noise-limited performance at temperatures near 300K. Under overcast, moonless conditions with photon flux 10^10 [ph cm-2 s-1] these limitations pose stringent requirements for dark current noise and uniformity. These requirements focus continued interest on reducing high-density, small-pitch focal plane array dark current. Analytical models, however, provide limited insight on root causes for performance bounds in this double heterostructure device. In this work we use three-dimensional numerical simulation to investigate diffusion-limited dark current for the planar InGaAs structure in 3x3 focal plane arrays with radiative recombination dominating the intrinsic recombination mechanisms. Under these conditions diffusion lengths, ranging from 20 to 40 um, exceed individual pixel pitch, so that nearest neighbors limit lateral diffusion currents in the array pixels. This numerical approach lets us investigate the influence of geometry on dark diffusion current, and provides a diagnostic tool to investigate correlations between observed behavior and root causes for arbitrarily specified architectures in this material system.

9070-4, Session 1

3D numerical simulation of planar P+n heterojunction In0.53Ga0.47As photodiodes in dense arrays, part II: Modulation transfer functions modeling

Adam R. Wichman, Boston Univ. (United States); Roger E. DeWames, Corbin Co. (United States); Enrico Bellotti, Boston Univ. (United States)

Current manufacturing has facilitated smaller pixel dimensions for lattice-matched InGaAs on InP short-wave infrared detectors, with recent demonstrations reporting feasibility for 5 um pixel arrays. Due to its technological maturity, this material system continues to gain attention for low-light level imaging applications. With pixel dimensions smaller than minority carrier diffusion lengths, crosstalk from lateral carrier diffusion remains important to the conventional array performance. Analytical models, however, provide limited insight on root causes for performance bounds in this double heterostructure device. In this work we develop a three-dimensional numerical simulation for dense P+n In0.53Ga0.47As on InP photodetector focal plane arrays using a conventional planar, back-illuminated structure. We evaluate optical generation with finite difference time domain analysis, and model carrier transport in a drift-diffusion analysis simultaneously solving the carrier continuity and Poisson equations. Using this model we investigate array modulation transfer function variations with pixel pitch and junction implant geometries for small dimension arrays. By accounting for diffusion effects, these results should provide a benchmark against which to evaluate modulation transfer function contributions from other effects, such as crosstalk attributable to photon recycling.

9070-5, Session 1

New developments on InGaAs focal plane array

Jerome Coussement, Anne Rouvie, El Houcine Oubensaid, Odile Huet, Sébastien Hamard, Jean-Patrick Truffer, Maxime Pozzi, Patrick Maillart, Eric M. Costard, Yann Reibel, Thibault Augey, SOFRADIR (France)

SWIR detection band benefits from natural (sun, night glow, thermal radiation) or artificial (eye safe lasers) photons sources combined to low atmospheric absorption and specific contrast compared to visible wavelengths. It gives the opportunity to address a large spectrum of applications such as defense and security (night vision, active imaging), space (earth observation), transport (automotive safety) or industry (non destructive process control).

InGaAs material appears as a good candidate to satisfy SWIR detection needs. The lattice matching with InP constitutes a double advantage to this material: attractive production capacity and uncooled operation thanks to low dark current level induced by high quality material.

The recent transfer of imagery activities from III-VLab to Sofradir provides a framework for the production activity with the manufacturing of high performances products: CACTUS320 and CACTUS640.

The developments, begun at III-Vlab towards VGA format with 15µm pixel pitch, lead today to the industrialization of a new product: SNAKE640. On one side, the InGaAs detection array presents high performances in terms of dark current and quantum efficiency. On the other side, the low noise ROIC has different additional functionalities. Then this 640x512 @ 15µm module appears as well suited to answer the needs of a wide range of applications.

In this paper, we will present the Sofradir InGaAs technology, some performances optimization and the last developments leading to SNAKE640.

9070-6, Session 1

Low-noise, small SWaP, SWIR imagers for light-starved high-sensitivity applications

Michael W. Delamere, UTC Aerospace Systems (United States)

High Sensitivity Megapixel and VGA shortwave IR imagers are presented. The imagers have 1280x1024 and 640x512 resolution FPAs with 12.5 µm pitch. The associated camera electronics are designed to optimize small SWaP and performance for a variety of applications including man-portable and airborne systems. Performance characterization of both these imagers is presented showing low-noise, high dynamic range capability suitable for challenging operational environments including light-starved and urban environments as well as a variety of industrial applications

9070-7, Session 1

Low-dark current 1024x1280 InGaAs PIN arrays

Ping Yuan, James J. Chang, Joseph C. Boisvert, Rengarajan Sudharsanan, Nasser H. Karam, Spectrolab, Inc. (United States)

Photon counting imaging applications requires low noise from both detector and readout integrated circuit (ROIC) arrays. In order to retain the photon-counting-level sensitivity, a long integration time has to be employed and the dark current has to be minimized. It is well known that the PIN dark current is sensitive to temperature and a dark current density of 0.5 nA/cm2 was demonstrated at 7 ºC previously. In order to restrain the size, weight, and power consumption (SWaP) of cameras for persistent large-area surveillance on small platforms, it is critical to develop large format PIN arrays with small pitch and low dark current density at higher operation temperatures.

In this paper we report on the growth, fabrication and testing of a 1024x1280 InGaAs PIN focal plane arrays with 12.5 µm pitch with less than 0.5 nA/cm2 dark current density at 15 °C. Based on our previous low-dark-current PIN designs, the improvements were focused on the epitaxial material design and growth control; and PIN device fabrication process to minimize the perimeter leakage current and junction diffusion current. We will present characterization data and analyses that illustrate the contribution of various dark current mechanisms. Furthermore, optical responsivity and pixel capacitance data that are also of critical importance to array sensitivity will be presented.

9070-8, Session 1

SWIR detectors for night vision at AIM

Heinrich Figgemeier, Matthias Benecke, Karl C. Hofmann, Reinhard Oelmaier, Alexander Sieck, Joachim C. Wendler, Johann Ziegler, AIM INFRAROT-MODULE GmbH (Germany)

Detectors for the SWIR spectral range are particularly suitable for observation under haze weather conditions or under twilight or moon light conditions. In addition SWIR detectors allow utilization of the airglow for observation under moonless sky. SWIR detectors are commonly based on InGaAs or HgCdTe, (MCT) respectively, demanding for extremely low dark current to ensure a high signal to noise ratio under low background conditions.

AIM has developed a Read-Out-Integrated-Circuit (ROIC) with 640x512 pixel and 15 µm pixel pitch for low light level applications. The ROIC supports internal or external correlated double sampling (CDS) for reduction of kTC-noise. Along with CDS a rolling shutter (RS) mode has been implemented. The input stage of the ROIC is based on a capacitive transimpedance amplifier (CTIA) with two selectable gain settings. The dark current of our SWIR MCT detectors has been significantly reduced recently to allow for high operating temperatures. In contrast to InGaAs, the MCT material offers the unique possibility to adjust the cut-off wavelength according to the application while maintaining the matching of the lattice constant to the CdZnTe substrate.

The electro-optical parameters of SWIR Focal Plane Arrays (FPA) with 1.8 µm cut-off wavelength have been measured and the key performance parameters will be presented.

9070-9, Session 1

High-performance SWIR HgCdTe FPA development on silicon substrates

Ramana Bommena, Jeremy D. Bergeson, EPIR Technologies, Inc. (United States); Priyalal S. Wijewarnasuriya, U.S. Army Research Lab. (United States); Nibir K. Dhar, Defense Advanced Research Projects Agency (United States); Richard Kodama, Jun Zhao, Fikri Aqariden, Silviu Velicu, EPIR Technologies, Inc. (United States)

HgCdTe is an attractive material that historically has been of interest primarily as the absorber material in photovoltaic detector applications at mid and long wavelengths. Recently there is growing interest in using HgCdTe for shorter wavelengths, because it provides the natural ability to tune the bandgap by adjusting the alloy composition for a broad range of wavelengths. So far, most research and development on NIR and SWIR imaging has focused on ternary and quaternary III V mixed crystals such as InGaAsP, InGaAs/InP, and AlGaAsSb. However, III V materials exhibit degraded performance for cutoff wavelengths longer than 1.7 µm due to an increasing lattice mismatch with the growth substrate. HgCdTe on the other hand maintains a nearly constant lattice parameter over the entire range of alloy composition. This study investigates the application of HgCdTe materials grown on Si substrates for extended SWIR band operation beyond 1.7 µm.

We report the development of high performance low cost SWIR infrared detectors from MBE-grown HgCdTe on 3" CdTe-buffered silicon substrates. The experimental findings demonstrate that despite the large lattice mismatch between HgCdTe and Si substrate, the materials and detector performances are sufficiently better than those reported for III V mixed crystals. High minority carrier lifetime of the order 3 μs at room temperature was measured on the as grown material. Photodetectors fabricated from this material produced low dark current densities on the order of 10 6 A/cm2 and 10 3 A/cm2 at 200K and 300K. Quantum efficiency exceeding 70% at 2.0 μm, without antireflective coating, was measured on single element detectors. Further, FPAs have been fabricated with this HgCdTe on Si material and imaging and radiometric characterization has been performed from 77K through room temperature.

9070-10, Session 1

A miniature VGA SWIR camera using MT6415CA ROIC

Selim Eminoglu, Gokhan S. Yilmaz, Serhat Kocak, Mikro-Tasarim Ltd. (Turkey)

No Abstract Available

9070-11, Session 2

Panoramic thermal imaging: challenges and tradeoffs

Shimon Aburmad, Opgal Optronic Industries Ltd. (Israel)

Over the past decade we have witnessed a growing demand for electro-optical systems that can provide continuous 3600 coverage. Applications such as perimeter security, autonomous vehicles, and military warning systems are a few of the most common applications for such Panoramic Imaging capability.

There are several different technological approaches for achieve Panoramic Imaging. Solutions which are based on rotating elements do not provide continuous coverage as there is a time lag between updated. Continuous panoramic solutions are either using "stitched" images from multiple adjacent sensors, or using sophisticated optical designs which warp a panoramic view onto a single sensor.

When dealing with panoramic imaging in the visible spectrum, high volume production and advancement of semiconductors technology enabled the use of CMOS/CCD image sensors with high pixel counts, small pixel dimensions, and low costs.

However, In the Infrared spectrum, the growth of the detector pixel counts, pixel size reduction, and cost reduction is happening at a slower rate due to the complexity of the technology and laws of physics.

In this work we will explore the challenges which are involved in achieving 3600 panoramic thermal imaging, and will analyze aspects such as spatial resolution, FOV's, data complexity, FPA utilization, system complexity, coverage and cost of the different solution types.

We will provide illustrations, calculations, and trade-offs between 2 solutions evaluated by Opgal : A unique 3600 lens design using an LWIR XGA detector, and the stitching of 3 adjacent LWIR sensors equipped with low distortion 1200 lens.

9070-12, Session 2

High-resolution panoramic images with megapixel MWIR FPA

Vincent Leboucher, HGH Systèmes Infrarouges (France)

Following its current strategy, HGH maintains a deep effort in developing its infrared panoramic 360-degree surveillance sensors. HGH's expertise with infrared surveillance technologies complies with various markets: perimeter surveillance of critical areas as well as situational awareness on watercrafts.

For two years, HGH has optimized and tested new MWIR panoramic sensors. The Spynel-S, a rotating infrared camera linked to a processing unit via a Gigabit Ethernet link which includes a cooled 640x512 pixels MWIR array, was released early this year.

HGH also improved its Cyclope software and redesigned its GUI. Cyclope now allows interfacing with other types of sensors (RADARs, AIS and PTZ cameras) and supervision systems. Distance estimation was improved taking into account a digital elevation model. Time stamps and a synthetic timeline were developed to ease forensic analysis of panoramic videos.

At the same time, HGH designed a new extra-large resolution sensor involving a MWIR megapixel FPA detector (1280x1024 pixels): the Spynel-X. It provides outstanding high-resolution 360-degree images (> 100Mpixels). The sensor required the development of a completely new data transfer and processing system. Images are pre-processed on a FPGA-DSP board, then transferred through a 10GigE optical fiber link and processed by a multi PC station.

Spynel-X will be tested this Autumn, 2013, in representative outside configurations including coastline surveillance on a semaphore. Its main characteristics are:

• Thermal resolution: NETD <30mK.

• Image resolution: 92000 (H) x 1280 (V) (for 5° VFOV configuration).

• Dimensions and weight: 385mm x 580mm, <40kg.

The mechanical frame of Spynel was designed in collaboration with an industrial design agency to give a technologic, robust and elegant aspect to the camera.

9070-13, Session 2

A long-range camera based on an HD MCT array of 12μm pixels

Douglas J. Davy, Stuart F. N. Ashley, Bryan Davison, R. Kennedy McEwen, Andrew P. Ashcroft, Richard Moore, SELEX ES Ltd. (United Kingdom)

The development of a new thermal imaging camera, for long range surveillance applications, is described together with the enabling technology. Previous publications have described the development of large arrays of 12μm pixels using Metal Organic Vapour Phase Epitaxy (MOVPE) grown Mercury Cadmium Telluride (MCT) for wide area surveillance applications. This technology has been leveraged to produce the low cost 1280x720 pixel Medium Wave IR focal plane array at the core of the new camera. Also described is the newly developed, high performance, x12 continuous zoom lens, which together with the detector, achieves an instantaneous field of view of 12.5 rad/pixel enabling long detection, recognition and identification ranges. Novel image processing features, including the turbulence mitigation algorithms deployed in the camera processing electronics, are also addressed. Resultant imagery and performance will be presented.

9070-14, Session 2

Experimental tomographic scanning (TOSCA) imagers

Harald Hovland, Forsvarets Forsknings Institutt (Norway)

The tomographic scanning (TOSCA) principle use signals detected using line detectors to scan a scene at regularly distributed angles. These line scan signals are then processed to reconstruct 2-dimensional images. In the simplest form, a 1-axis rotating conical scan optics scans across a simple patterned reticle, the signal collection being done with a single pixel detector. An experimental multispectral camera using this approach has

been demonstrated in the visible region, and gives a fundamental insight into the imaging properties of conical scan sensors, which have been popular in use as hot-spot trackers. A significantly different array based approach is demonstrated to work in the infrared region. The presentation will go through the inner workings of the TOSCA principle, and signals extracted and videos made from imaging scenes will demonstrate several unique aspects of TOSCA imagers, such as the inherently perfect alignment of multispectral channels in such an imager, and the capability of handling light modulation in the scene with frequencies higher than the frame rate.

9070-16, Session 2

Time-resolved multispectral imaging

Frédérick Marcotte, Vincent Farley, Telops (Canada)

For years, scientists have been using broadband cameras to perform measurements in the infrared spectral bands. In order to improve the outcomes of these studies, Telops has developed a fast multispectral imaging system in the LWIR and MWIR band.

This paper presents the improvement that a fast infrared multispectral imager adds to the traditional infrared investigations and how this system can be applied in defence innovation research. An overview over the technology is presented and discussed along the results obtained during a combustion experiment.

9070-17, Session 2

Infrared light-field imaging using single carbon nanotube (CNT) detector

Ning Xi, Michigan State Univ. (United States)

The conventional photographs only record the sum total of light rays of each point on image plane so that they tell little about the amount of light traveling along individual rays. The focus and lens aberration problems have challenged photographers since the very beginning. This problem becomes more serious in infrared imaging. The light field photography was proposed to solve the problem. Lens array and multiple camera systems were used to capture angular information, by reordering which the different views of scene were captured. The coded aperture is another method to encode the angular information in frequency domain. However, lens aberration still is an inescapable problem when acquiring angular image. In the paper, we propose micro plane mirror optics, together with compressive sensing algorithm to record angular information to avoid aberration problem. The micro mirror reflects objects and forms a virtual image behind the plane in which the mirror lies. It consists of millions microscale mirror which works as CCD array in camera and it was controlled separately so as to project linear combination of object image on lens array. The carbon nanotube based infrared detector, which has low thermo noise, high signal to noise ratio, and fast responsibility, will sum up all image information on it, without image shape effect. Based on a number of measurements, compressive sensing algorithm was used to recovery angular image, and computed different views of scene to reconstruct an infrared light field image.

9070-18, Session 2

Thermal imaging as a smartphone application: Exploring and implementing a new concept

Omer Yanai, Opgal Optronic Industries Ltd. (Israel)

Today's world is going mobile. Smartphone devices have become an important part of everyday life for billions of people around the globe.

Thermal imaging cameras have been around for half a century and are now making their way into our daily lives. Originally built for military applications, thermal cameras are starting to be considered for personal use, enabling enhanced vision and temperature mapping for different groups of professional individuals.

Through a revolutionary concept that turns smartphones into fully functional thermal cameras, we have explored how these two worlds can converge by utilizing the best of each technology.

We will present the thought process and conclusion of our development process, resulting in a low-power, high resolution, lightweight USB thermal imaging device that fits any smartphone and requires literally no calibration.

We will show the implications of this device on thermal imaging technology, making it more accessible to a wider audience. Through the implementation of common practices taken from the mobile world, we will explore how an eco-system of developers and users may evolve around this concept. We will then highlight the main technology and go-to-market differences between this new concept and other attempts to mobilize thermal technology, highlighting their respective pluses and minuses.

We will also provide a live demonstration using a clip-on thermal imaging device connected to an Android based smartphone, and will share some insights and challenges we came across during this development process. Finally, we will discuss the opportunities that this innovative technology brings to the market.

9070-19, Session 2

Case studies: using infrared technology for evidentiary purposes

John Lester Miller, Noel D. Jolivet, Joel Hansen, FLIR Systems, Inc. (United States); Rico Beniga, Postland Police Dept. (United States); Rich Austria, Portland Police Dept. (United States)

Infrared technology and imaging systems are already used extensively by the law enforcement (LE) community, typically to gain a tactical advantage or obtain immediate situational awareness. As the use of infrared technology becomes more affordable and widespread, LE is finding new ways to use it and leverage the results in the courtroom as evidence. A case study will be presented where infrared imagery was used to support the Portland Police Bureau (PPB) in prosecuting an individual for a crime where a conviction might not have been assured without said imagery. Tests conducted at FLIR Systems combined with expert witness testimony by a FLIR employee helped a jury understand the significance of a key piece of infrared evidence, resulting in a conviction of the criminal. This case was the first Federal case of its kind where infrared imagery was used forensically as evidence and, as such, established precedence. Prior to this, infrared imagery has been offered and debated in court only as to whether it constitutes a legal search. Courtroom observations and lessons learned from trials have shown that both industry and LE can do a better job of making the prosecution's cases stronger utilizing infrared technology and thus taking criminals off the street.

9070-135, Session 2

Color night vision system for ground vehicle navigation

Ehsan Ali, Hemain Qadir, Samuel Kozaitis, Florida Institute of Technology (United States)

Operating in a degraded visual environment due to darkness can pose a threat to navigation safety. Systems have been developed to navigate in darkness that depend upon differences between objects such as temperature differences or reflectivity at various wavelengths. Such systems use a combination of passive and active sensors to discriminant between objects. However, adding sensors increases the complexity of a system by adding multiple components that may create problems with alignment and calibration. An approach is needed that is passive and simple for widespread acceptance.

We considered a system that depends to some degree on what is expected. For example, when driving a ground vehicle, a road is typically at the

bottom of a scene, and the sky is at the top. We used this concept to aid the development of a passive system for to improve safety while driving a ground vehicle at night. Our approach used a type of augmented display for operating in a degraded visual environment that is continuously updated. A publically available dataset filled in the regions of the thermal imagery when there was no signal, and an image fusion method was used where there was a thermal signal. Using this approach, we were able to produce imagery acquired at night that appeared as if in the daylight. Such an approach could improve the safety of nighttime navigation.

9070-20, Session 3

Cooled IR detectors for military and space applications at i3system

Sooho Bae, Young-Ho Kim, Byung-Hyuk Kim, Ho-Jun Lee, Han Jung, i3system, Inc. (Korea, Republic of)

This paper shows the current status of cooled IR detector technologies at i3system, South Korea. Mass production technology of i3system has successfully supplied thousand units of QVGA cooled IR detectors to Korean military system since 2010. i3system has small pitch cooled IR detectors with 320x256 and 640x512 formats for several different applications such as thermal sights and 24-hour operation observation units. Also, our cooled IR detector has been launched in STSAT-2C satellite through KSLV-I program on 2013 which was South Korea's first launch vehicle for satellite. Owing to our robust and intensive development and test programs, our detector technologies have been space qualified without any further efforts. Currently, development programs for SXGA cooled detector are being progressed and its preliminary performances are addressed.

9070-21, Session 3

Cooled and uncooled infrared detectors for missile seekers

Udi Mizrahi, Rami Fraenkel, Jacob Haski, Lior Shkedy, Itay Shtrichman, SCD Semiconductor Devices (Israel)

Electro-optical missile seekers pose exceptional requirements for infrared (IR) detectors. These requirements include: very short mission readiness (time-to-image), one-time and relatively short mission duration, extreme ambient conditions, high sensitivity, fast frame rate, and in some cases small size and cost.

SCD is engaged in the development and production of IR detectors for missile seeker applications for many years. 0D, 1D and 2D InSb focal plane arrays (FPAs) are packaged in specially designed fast cool-down Dewars and integrated with Joule-Thomson (JT) coolers. These cooled MWIR detectors were integrated in numerous seekers of various missile types, for short and long range applications, and are combat proven. New technologies for the MWIR, such as epi-InSb and XBn-InAsSb, enable faster cool-down time and higher sensitivity for the next generation seekers.

The uncooled micro-bolometer technology for IR detectors has advanced significantly over the last decade, and high resolution - high sensitivity FPAs are now available for different applications. Their much smaller size and cost with regard to the cooled detectors makes these uncooled LWIR detectors natural candidates for short and mid-range missile seekers.

In this work we will present SCD's cooled and uncooled solutions for advanced electro-optical missile seekers.

9070-22, Session 3

A new joint laboratory between SOFRADIR and ONERA for the development of advanced DDCA with integrated optics

Guillaume Druart, Nicolas Guérineau, ONERA (France); Yann Reibel, Serge Magli, Noura Matallah, SOFRADIR (France)

Today, both military and civilian applications require miniaturized optical systems in order to give an imagery function to vehicles with small payload capacity. After the development of megapixel focal plane arrays (FPA) with micro-sized pixels, this miniaturization will become feasible with the integration of optical functions in the detector area. In the field of cooled infrared imaging systems, the detector area is the Detector-Dewar-Cooler Assembly (DDCA). A dewar is a sealed environment where the detector is cooled on a cold plate.

SOFRADIR and ONERA have launched a new research and innovation partnership to develop disruptive technologies for DDCA to improve the performance and compactness of optronics systems. With this collaboration, we will break down the technological barriers of DDCA, a sealed and cooled environment dedicated to the infrared detectors, to allow the investigation of optical designers to bring advanced optics inside the DDCA. This technological breakthrough will bring more compact multipurpose thermal imaging products, as well as new thermal capabilities such as 3D imagery or multispectral of hyperspectral imagery.

The previous developments will be recalled (The cameras SOIE and FISBI, the on-chip camera...) and the future trends will be presented.

9070-23, Session 3

Smart filters: from VIS/NIR to MW/LWIR protection

Ariela Donval, Tali Fisher, Ofir Lipman, Moshe Oron, KiloLambda Technologies, Ltd. (Israel)

New development of imaging systems implies the use of multi band wavelength, VIS, NIR, MW and LW, for imaging enhancement and more data presenting. Some of those systems, such as < see spot>, are designed for applications requiring in plus, the ability to see the aiming point of a laser designator.

The use of laser ‹see spots› to assist in target identification and tracking can unintentionally result in a laser beam reflected back into the sensor, leading to transient dazzling or permanent damage of the sensor. This scenario can lead to non-operation optical imaging system.

The need to protect the system from the same kind of laser it is required to observe, is presenting an engineering challenge. The usual spectral filter solution is obviously not suitable in this case, since it will block completely the same laser wavelength range required for designation.

We propose a novel passive solid-state threshold-triggered Wideband Protection Filter (WPF) that blocks the transmission only if the power exceeds a certain threshold. As opposed to fixed spectral filters, which permanently block only specific wavelengths, the wideband filter is clear at all wavelengths until hit by damaging light. We propose a new solution based on laser energy threshold activation, rather than wavelength dependent activation. Wideband Protection Filter (WPF) is a totally passive filter-layer exhibiting transparency at all wavelengths including the visible and IR ranges. However, when struck by high power lasers, the filter undergoes a transformation at the exact point of the impinging rays, restricting their passage, while other areas of the filter are unaffected and enable the acquisition of the image using a thermal imaging system. The WPF can provide a suitable solution for optical imaging systems, which are open for the wavelength region of the laser designator. We present a special design of WPF suitable for dual- and multi- band wavelength range, including transmission and functionality performances

9070-24, Session 4

Antimonide-based superlattices for LWIR imaging *(Invited Paper)*

Manijeh Razeghi, Northwestern Univ. (United States)

In recent years, the narrow-bandgap antimonide-based semiconductors are widely regarded as one of the strong candidate material systems for fabrication of the third generation of infrared imagers and integrated circuits with ultra-high speed and ultra-low power consumption. Antimonide-based semiconductors mainly refer to the binary, ternary, and quaternary compound semiconductors, such as GaSb, InSb, AlSb, InAsSb, InSbBi, InTlSb, and InTlAsSb. Furthermore, antimonide-based semiconductors can be used to form artificial quantum structures such as GaSb/InAs, InAs/InAsSb, or InAs/AlSb/GaSb type-II superlattices.

Study of different antimonide-based semiconductors for infrared detection and emission applications has been an active field of research at Center for Quantum Devices (CQD) for more than two decades. These efforts cover almost all members of antimonide-based semiconductors family from simple binary compounds, such as InSb, to complicated quaternary ones like InTlAsSb. In the other hand, antimonide-based type-II superlattices have been subject of extensive studies at CQD. These studies resulted in demonstration of infrared photodetectors and imagers which can cover infrared spectrum from 1.5 to longer than 32μm.

This talk will cover the latest results and Best solution for high performances, large format, multicolor LWIR imaging.

9070-25, Session 4

InAs/GaSb superlattice detectors for the long wavelength infrared regime

Robert Rehm, Jan-Michael Masur, Johannes Schmitz, Jasmin Niemasz, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany); Petra Fries, Detlef Eich, AIM INFRAROT-MODULE GmbH (Germany); Martin Walther, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany)

Over the last few years, InAs/GaSb superlattice (SL) infrared (IR) detectors have shown tremendous progress both in the mid-wavelength (MWIR, 3-5 μm) and in the long-wavelength (LWIR, 8-12 μm) atmospheric windows. Favorable fundamental properties like, e.g., a widely adjustable bandgap, a high quantum efficiency and low dark current render the InAs/GaSb SL material into an attractive alternative to CdHgTe or InSb-based devices, which are widely used for high-performance IR detectors and imagers. Recently, various groups have taken advantage of the flexibility in the InAs/GaSb/AlSb material system to engineer device concepts with advanced bandstructures, which significantly pushed the electrooptical performance.

For the LWIR regime, we predominantly develop InAs/GaSb SL detectors based on heterojunction device concepts. Today, this approach is considered most efficient for increasing the operating temperature of imaging cameras. The bandstructure calculations, which guide our device design, have been undertaken with a refined version of the Superlattice Empirical Pseudopotential Method (SEPM) that we painstakingly verified. The proof of concept was achieved with first heterojunction devices showing more than one order of magnitude lower dark current compared to conventional homojunction devices with the same absorber bandgap along with quasi bias-independent quantum efficiency at low operating voltage. Successive heterojunction device designs are expected to achieve further reduced dark current. In order to demonstrate the imaging performance of the LWIR InAs/GaSb SL heterojunction devices, the wafers are processed into detector arrays with 640x512 pixels at 15 μm pitch and hybridized to a custom-designed read-out integrated circuit (ROIC) by standard Indium-bump flip chip technology.

9070-26, Session 4

InAs/GaSb Type II superlattice barrier devices with a low dark current and a high-quantum efficiency *(Invited Paper)*

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Type II InAs/GaSb superlattices (T2SLs) are a promising III-V alternative to HgCdTe for infrared Focal Plane Array (FPA) detectors. Over the past few years SCD has invested a considerable effort in the modeling, growth, processing and characterization of high performance T2SL detector structures suitable for FPA fabrication. Our LWIR structures are based on an XBp design, analogous to the XBn design that lead to the recent launch of SCD's InAsSb HOT MWIR detector (TOP= 150 K). The T2SL XBp structures have a cut-off wavelength of ~9.5 μm and are diffusion limited with a dark current at 78K that is within one order of magnitude of the MCT Rule 07 value. We demonstrate 30 μm pitch 5 x 5 test arrays with 100% operability and with a dark current activation energy that closely matches the bandgap energy measured by photoluminescence at 10 K. From the dependence of the dark current and photocurrent on mesa size we are able to determine the lateral diffusion length and quantum efficiency (QE). The QE agrees very well with the value predicted by our recently developed k.p model [Livneh et al, Phys. Rev. B86, 235311 (2012)]. The model includes a number of innovations that provide a faithful match between measured and predicted T2SL bandgaps from MWIR to LWIR, and which also allow us to treat other potential candidate systems with strong bandgap bowing, such as the Gallium free InAs/InAsSb superlattice (GFSL). We will present a critical comparison of GFSL vs. T2SL for LWIR FPA applications.

9070-27, Session 4

Development of bi-spectral InAs/GaSb type II superlattice image detectors *(Invited Paper)*

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InAs/GaSb superlattices are characterized by a broken-gap type II band alignment. Their effective band gap can be engineered to match mid to far infrared (IR) photon energies by selecting appropriate layer thicknesses during crystal growth. Fraunhofer IAF, with its expertise in growing such structures by molecular beam epitaxy (MBE) and through the development of a mesa insulation process complemented by a proprietary passivation technology, has been instrumental in establishing the potential of the material system for high performance IR photodiodes.

Together with our industry partners, we have developed this technology into image detectors capable of spatially and temporally coincident detection in two mid IR wavelength ranges and built up the capacity for small-scale production of such detectors to support specific applications in threat warning systems.

We review the present status of the processing technology and report continuous improvements achieved in key areas of detector performance, including defect density and noise behavior. Recently developed measurement techniques enable the characterization of ensembles of individual detector elements at device operating temperature and we present initial statistical results for diode characteristics and noise properties. Such data facilitates assessment of detectors before sensor assembly and can be related to process parameters and sensor performance as well as to predictions from theoretical models. Identified correlations form a basis for further device and process optimization.

9070-28, Session 4

Comparison of the electro-optical performances of MWIR InAs/GaSb superlattice pin photodiodes with symmetrical and asymmetrical designs

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Asymmetrical InAs/GaSb superlattice (SL) pin photodiodes were recently proposed to both decrease the dark current (since it should decrease the intrinsic carrier concentration) and increase the quantum efficiency (since it should increase the wavefunctions overlap) of MWIR SL photodetectors.

An improvement of more than one decade on the dark current has already been demonstrated. In this paper, we show that the quantum efficiency doesn't reach the expected values : the "InAs-rich" devices (with 7.5 InAs monolayers (ML) and 3.5 GaSb MLs in each period) indeed exhibit a lower quantum efficiency than the symmetrical devices at 0V bias voltage. Moreover, the quantum efficiency of this asymmetrical device strongly depends on the bias voltage. To state on this puzzling behavior, we report measurements of quantum efficiency as a function of wavelength and bias voltage for several devices : first of all, we compare a symmetrical one, an InAs-rich asymmetrical one and a GaSb-rich asymmetrical one, all of them with an active zone thickness of 1µm. Then we compare InAs-rich devices with different active zone thicknesses (0.5, 1 and 4µm). All these devices exhibit a cut-off wavelength of 5µm @ 80K. Our experimental results are interpreted thanks to a fully analytic model which predicts the quantum efficiency of our PIN photodiodes. We point out that the low quantum efficiency values at 0V and the dependence of the quantum efficiency on the bias voltage are due to a non optimal transport of carriers.

9070-29, Session 5

On the origin of 1/f noise in electronic devices
(Keynote Presentation)

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No Abstract Available

9070-30, Session 6

MWIR superlattice detectors integrated with substrate side-illuminated plasmonic coupler

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Signal-to-noise ratio (SNR) of mid-wave infrared (MWIR) detectors based on InAs/GaSb strained layer superlattice (SLSs) may be significantly enhanced at selected wavelengths by integrating the detector with a back-side illuminated plasmonic coupler. The application of a simple metal-SLS structure directly on the GaSb substrate can result in radiation losses into the substrate due to the low refractive index of SLS layer, however, insertion of a higher refractive index material, such as germanium (Ge), into the metal-SLS structure can confine the surface plasmon waveguide (SPW) modes at the surface.

In this work, metal (Au)-Ge-SLS structures were designed with varied Ge layer thicknesses. The SLS layer utilized a p-i-n detector design with an InAs top contact (10 nm), GaSb bottom contact (100 nm), and a SLS absorption region (100 nm) consisting of 8 monolayers (MLs) InAs/8 MLs GaSb. Single element SLS detectors with 410 µm x 410 µm mesa area were fabricated using standard optical lithography and dry etching techniques. A plasmonic coupler was then realized inside the 300 µm circular apertures of these single element detectors by the formation of a corrugated metal (Au) surface.

The SLS single element detector integrated with an optimized plasmonic coupler design increased the quantum efficiency (QE) by a factor of three at an operating temperature of 77 K and 4 µm illumination wavelength compared to a reference detector structure, and each structure exhibited the same level of dark current. Further performance considerations and improvements for a SLS single element detector design integrated with the plasmonic coupler will be discussed during the presentation.

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9070-31, Session 6

Pretreatment for surface leakage current reduction in type-II superlattice MWIR photodetectors

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Focal plane array based on type-II InAs/GaSb superlattice (T2SL) is expected as an alternative to HgCdTe. In order to improve the performance of T2SL detector, it is important to build a reliable fabrication process. Especially, mesa formation and passivation with understanding of surface leakage mechanism is critical issue. Generally, the existence of dangling bonds at crystal surface or damaged layer and native oxides on etched mesa sidewall leads to surface leakage currents, which mostly degrade the detector performance. Many researchers adopted SiO2 film as an effective passivation layer, which was deposited by plasma enhanced chemical vapor deposition at low temperature. However, good passivation requires not only stable film, but also an effective surface treatment before passivation.

In this work, we present dry etching mesa formation and the effect of pretreatment of passivation on the performance of T2SL p-i-n photodiode fabrication.

T2SL was grown on GaSb:Te substrate using molecular beam epitaxy method. The photodiodes have a p-i-n structure. Mesa structure was formed by inductively coupled plasma reactive ion etching with halogen gas mixture. Prior to SiO2 passivation, treatments such as phosphoric acid, NH4OH wet cleaning and dry cleaning were conducted. From I-V measurements of the variable area test diodes, we estimated the bulk limited R0A value and surface resistivity of the pretreated and untreated samples. It was found that dry cleaning was more effective to surface leakage reduction. Results of electrical and optical characterization of these devices will be discussed

9070-32, Session 6

Passivation of long-wave infrared InAs/GaSb superlattice detectors with epitaxially grown ZnTe

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In past decade, T2SL detectors with promising performance have been reported by various institutions thanks to the extensive modeling efforts, improvement of T2SL material quality, and development of advanced low-dark-current architectures with unipolar barriers (Xbn, CBIRD, pBiBn, M-structure, etc).

One of the most demanding challenges of present day T2SL technology is the suppression of surface leakage currents associated with the exposed mesa sidewalls, which appear during the definition of device optical area. Typical FPA pixels with dimensions of ~20um x 20um have large surface/volume ratio and their performance is strongly dependent on surface effects. In order to overcome the limitation imposed by surface leakage currents, a stable surface passivation layer is needed.

In this paper we report on InAs/GaSb T2SL detectors operating in the LWIR spectral region (100% cut-off wavelength of ~9.8μm at 77K) passivated with epitaxially grown ZnTe. In order to compensate for the high conductivity of ZnTe passivation it was doped with chlorine to 1 x 10^18cm^?3 concentration. Dark current measurements reveal the significant reduction of noise current after ZnTe passivation. The passivated circular mesa device with 50 μm diameter demonstrated dark current of 3.2 x 10^-5 A/cm^2 at 77K and bias of -100mV. The performance details of T2SL LWIR detector passivated with ZnTe will be discussed during the presentation.

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9070-33, Session 6

Defect-related dark currents in III-V MWIR nBn detectors

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The effect of defects on the dark current characteristics of MWIR, III-V nBn detectors has been studied both theoretically and experimentally. Two different types of defects are compared, those produced by lattice mismatch and by proton irradiation. The performance of nBn detectors are compared to that of more standard, pn-junction based photodiodes. The dependence of dark current density on defect concentration, temperature, and applied voltage are examined.

It is shown that the effects on dark currents are similar, regardless of the type of defects induced. Introduction of defects always elevates dark currents; however the effect on dark current is different for nBn detectors and conventional photodiodes. Defect-related currents in photodiodes are found to be proportional to the defect concentration, while defect-related currents in nBn detectors scale as the square root of the defect concentration indicating that nBn's are more weakly affected by defects. Additionally, the thermal activation energies of defect currents in conventional photodiodes are generally and approximately half the bandgap energy but are always near the full bandgap for nBn detectors.

It is also shown that the experimentally measured dark current and its dependence on temperature, voltage, and defect concentration are consistent with classical Shockley-Read-Hall (SRH) generation models. In conventional photodiodes, the measured defect-related dark currents are well described by a model of SRH generation in the depletion region, resulting in the production of drift current. In nBn detectors, the results are consistent with SRH generation in the neutral, n-type absorber region, through which diffusion current is produced.

Finally, it is observed that the RoA values of nBn detectors are unchanged by the introduction of defects, despite the fact that the dark currents at operating voltages are increased by the presence of defects. As a result, RoA is not a useful parameter for gauging the performance of nBn detectors.

We find that compared with conventional photodiodes, the dark currents of nBn detectors are found to be more tolerant of defects produced by lattice mismatch and by irradiation. Defects more weakly increase dark currents in nBn detectors compared to pn-junction based devices, and cooling reduces the defect-produced dark currents more rapidly in nBn detectors than in conventional photodiodes.

9070-34, Session 6

Low dark current "N" structure superlattice MWIR photodetectors

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Commercially available read out integrated circuits (ROICs) require the FPA to have high dynamic resistance area product at zero bias (R0A) which is directly related to dark current of the detector. Dark current originates from surface and bulk contributions. Recent studies on band structure significantly suppressed the bulk contribution of the type-II superlattice infrared photodetectors (N structure, M structure, W structure). In this report, we will present improved dark current values for unipolar barrier complex supercell superlattice system which is called as "N structure". The unique electronic band structure of the N structure increases electron-hole overlap under bias, significantly. N structure aims to improve absorption by manipulating electron and hole wavefunctions that are spatially separated in type-II superlattices, increasing the absorption while decreasing the dark current. In order to engineer the wavefunctions, we introduce a thin AlSb layer between InAs and GaSb layers in the growth direction which also acts as a unipolar electron barrier. Despite the difficulty of perfect lattice matching of InAs and AlSb, such a design is expected to reduce dark current. Experiments were carried out on single pixel with mesa sizes of 100x100 – 700x700 μm2 photodiodes. Temperature dependent dark current with corresponding R0A resistance values are reported. The dark currents presented in this study are at least an order of magnitude lower than previous work.

9070-35, Session 6

New model for the ideal nBn infrared detector

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We have been using a synergistic combination of finite-element numerical simulations and analytical modeling to determine quantitatively the device physics and operation of ideal back-illuminated InAs-based nBn infrared detectors having a simplified configuration. By "ideal" nBn we mean that the operation and performance are governed only by fundamental inherent mechanisms: the only current mechanism is diffusion current and the only recombination mechanisms are Auger-1 and traditional radiative. The configuration is simplified in that the n-type absorber and contact layers have the same doping concentration and are of comparable thickness. The motive is to understand how the ideal simplified nBn detector operates and to provide useful limiting expressions for the J(V) and QE(V) characteristics to which actual nBn data can be compared. Our numerical simulations have led to a new quantitative analytical model for the ideal simplified nBn detector. The new feature of this model is the key role that hole transport across the thin wide-gap barrier layer plays in determining the J(V) and QE(V) characteristics. The new model is applicable to either a p-type or an n-type barrier layer. The simulations and new analytical model elucidate the overwhelming importance of the electrical type and doping concentration of the barrier layer to the operation of the nBn detector, particularly the amount of bias voltage necessary to overcome the valence band barrier when the barrier layer is n-type.

9070-36, Session 6

Performance comparison of barrier detectors and HgCdTe photodiodes *(Invited Paper)*

Piotr Martyniuk, Antoni Rogalski, Military Univ. of Technology (Poland)

No Abstract Available

9070-37, Session 7

Growth and characterization of 6" InSb substrates for use in large-area infrared-imaging applications

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In this paper we report on an industry first; the commercial growth and characterization of 6" diameter InSb substrates that are suitable for use in the fabrication of MWIR focal plane infrared detectors. Results will be presented on the production of single crystal 6" InSb ingots grown by the Czochralski (Cz) technique, supported by the analysis of bulk material quality by X-ray diffraction (XRD). We will also assess the electrical quality of new 6" InSb crystals and present uniformity information on Hall mobility, resistivity and carrier level from which we will infer comparisons on the relative dark current performance of the material grown. High quality, epitaxy-ready type surfaces have been prepared and we will demonstrate how the key surface quality characteristics of roughness (< 0.5 nm rms), oxide thickness (<20 Å) and flatness (<7 μm TTV) have been maintained across production processes that scale 4" to 6" wafer formats. We conclude by presenting our road map for the development of large area InSb substrates and describe how developments in Czochralski crystal growth and surface finishing technology will support industry's requirements to deliver higher performance, large format IR focal plane array type devices.

9070-38, Session 7

Multiwafer growth of GaInAs photodetectors on 4" InP by MOCVD for SWIR imaging applications

Mark J. Furlong, Mark Mattingley, Sung Wook Lim, Matthew Geen, Wynne Jones, IQE IR (United Kingdom)

Photodiodes based on the GaInAs/InP material system responding in the 1.3-1.7 μm wavelength range are of interest in a wide range of applications, from optical power and channel monitors in telecommunication systems through to advanced night vision imaging using large format focal plane type detectors for defence and security applications. Here we report on our results of GaInAs PIN photo detector structures grown on 2", 3" and 4" InP by low pressure Metalorganic Chemical Vapor Deposition (MOCVD) in both a standard (8 x 4") and new large volume format (12 x 2", 3" or 4") reactor configurations. High quality, lattice matched InP/GaInAs epitaxial layers were grown and we demonstrate that when moving from an 8 to 12 wafer configuration, high degrees of thickness uniformity (<3%, FTIR), lattice mismatch (<0.1%, XRD) and compositional uniformity (<2 nm, PL) can be maintained. The surface quality of epitaxial wafers will be assessed by various surface analytical techniques. We also make comparisons with the performance of 3" photodetector structures grown, this demonstrating that MOCVD production processes have been successfully scaled. We conclude by discussing the material requirements for large area infrared focal plane array photodetectors and describe how MOCVD growth technology will address industry's requirements for increasing device sizes with improved performance.

9070-39, Session 7

Characterization of moldable glasses for imaging lenses in the short-wave infrared (SWIR)

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The growing demand for short wave infrared (SWIR) sensors and cameras has focused attention on the need for lower cost optics in this infrared region. Traditional low Tg moldable glasses typically stop transmitting in the SWIR region. New low dispersion, moldable glasses have been found that transmit through 3 microns and in combination with Precision Glass Molding (PGM) can bring this enabling technology to SWIR optics.

This investigation reviews the material performance for a potential moldable solution in the SWIR range. Material properties including coefficient of thermal expansion, index of refraction, transmission and change in index over temperature are explored. Specific attention is given toward glasses that achieve high yields during precision glass molding and are candidates for commercial success.

9070-40, Session 7

Examination of laser-induced heating on multi-component chalcogenide glass

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Chalcogenide glasses have been well known to have good transparency into the infrared spectrum. They do however have lower thresholds for photo- and thermal- induced changes including photo-expansion, refractive index changes, mechanical property changes, crystallization, and ablation [1,2]. These changes can be induced by laser irradiation, which can allow one to be able to spatially modify the materials properties by moving either the beam or the sample. This control of material properties could lead to next-generation IR optical components. In the following study experiments were performed to assess various changes in the material used by exposing the material to different laser irradiation conditions in order to understand the effects of these conditions on material property changes. Thresholds of some of these changes were also investigated, with a main focus on photo-expansion and ablation by varying the exposure time and power. Simulations were then subsequently performed to try to estimate the temperature increase from the irradiation using various computational methods. The stability of the simulations with respect to material property values and computational tolerances was also looked into. These simulations can then be used to help de-convolve whether observed changes were optically or thermally induced. They can also be used to help to be able to predict expected changes in a material due to given laser irradiation conditions.

[1] "Direct femtosecond laser writing of optical waveguides in As2S3 thin films," A . Zoubir, et. al., Optics Letters 29 7 (2004)

[2]"Effect of IR femtosecond laser irradiation on the structure of new sulfo-selenide glasses", L. Petit, et. al., Optical Materials 29 1075–1083 (2007)

9070-41, Session 7

Laser damage resistant multiband high-reflective optics

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Diamond-turned Aluminum has been extensively used for infrared optical systems due to its light weight and broadband spectral performance. Dialectical multilayer coatings, on the other hand, offer high laser damage resistance with relatively narrowed spectral bandwidth. Combining dielectric multilayer coatings with diamond-turned Aluminum enables one to derive Aluminum based laser damage resistant multiband high reflective optics. In this contribution, spectral performance of laser durable coatings is presented with a spectral coverage from the visible to the IR at various angles of incidence. Coating design and deposition process were evaluated via atomic force microscopy, white light interferometry as well laser-induced damage threshold test performed at 1064 nm, 20 ns and normal angle of incidence. A laser-induced damage threshold of up to 19.5 J/cm2 was realized. In addition, laser-induced damage morphology was revealed by scanning electron microscopy along with a focus ion beam cutting for damage cross-sectional images. The damage mechanism was discussed in terms of nodular defect formation during film growth and ejection under laser irradiation.

9070-109, Session Posters-Tuesday

Extended wavelength InGaAs infrared detector arrays based on three types of material structures grown by MBE

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Extended wavelength InGaAs infrared detector arrays in 1.0~2.5μm spectral rang based on three types of material structures grown by MBE were studied. The first type InGaAs detectors, marked by sample 1#, were fabricated using P-i-N epitaxial materials, mesa etching technique, side-wall and surface passivating film. The second type InGaAs detectors, marked by sample 2#, were fabricated using N-i-P epitaxial materials, mesa etching technique, side-wall and surface passivating film. The third type InGaAs detectors, marked by sample 3#, were fabricated using n-i-n epitaxial materials, planar diffusion process and surface passivating coating. I-V curves, low frequency noise and response spectra of these detectors were measured at the different temperature. The response spectra of these detectors cover 1.0~2.5μm wavelength range. The dark current density of three types InGaAs detectors are 28nA/cm2, 2?A/cm2, 9?A/cm2 at 200K and -10mV bias voltage, respectively. Sample 1# shows the lowest dark current at the same temperature and the same bias voltage as Sample 2# and Sample 3#, which mainly results in the improvement of surface passivation film and the depth of mesa etching. The frequency spectrum of the noise of sample 1# has an inflection point at about 10Hz frequency, 1/f noise play an obviously role in the detectors below the 10Hz frequency.

9070-110, Session Posters-Tuesday

An uncooled capacitive sensor for IR detection

Georg Siebke, Kathrin Gerngroß, Peter Holik, Sam Schmitz, Markus Rohloff, Simon Tätzner, Siegfried Steltenkamp, Ctr. of Advanced European Studies and Research (Germany)

The beetle Melanophila acuminata detects forest fires from distances as far as 80 miles away. To accomplish this, the beetle uses highly specific IR receptors with a diameter of approximately 15 μm. These receptors are mechanoreceptors that detect deformations induced by the absorption of radiation. Although the detection mechanism is understood in principle, it is still unclear how the beetle reaches such high sensitivity.

In this work, we present the biomimetic approach of an uncooled IR sensor based on the beetle's receptors. This sensor is based on a fluid-filled pressure cell and operates at room temperature. Upon absorbing IR radiation, the fluid heats up and expands. The expanding fluid deflects one electrode of a plate capacitor. By measuring the change in capacitance, the volume increase and the absorbed energy can be inferred. To prevent the risk of damage at high energy absorption, a compensation mechanism is presented in this work. The mechanism prevents large but slow volume changes inside the pressure cell by a microfluidic connection of the pressure cell with a compensation chamber. The channel and the compensation chamber act as a microfluidic low-pass filter and do not affect the overall sensitivity above an appropriate cut-off frequency. Using MEMS technology, we are able to incorporate the complete system into a silicon chip with an area of a few mm?. Here, we show a proof-of-concept and first measurements of the sensor. With model calculations at hand, we will present an optimized sensor layout with respect to a maximized sensitivity.

9070-111, Session Posters-Tuesday

Temperature dependence of junction performance for mid-wavelength n-on-p HgCdTe detectors by laser beam-induced current microscope

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HgCdTe-based photodiodes are widely used in the fabrication of various infrared detectors for military and civil purposes. However, the performance of HgCdTe infrared photodetector is still easily affected by different defects and complex doping mechanism in the manufacturing process. So, the device yield of HgCdTe based IRFPAs is very low. Currently, Laser-beam-induced-current (LBIC) measurements as a high-resolution, nondestructive optical technique have been applied to characterize the opto-electrical property of junction at intermediate processing stage, which could significantly promote efficiency and save costs.

It has been found that there was n-type inversion region extension in different long-wave HgCdTe photodiodes at low temperature (87K) comparing with that at room temperature (300K). In this paper, we report on the disappearance of photosensitive area extension effect and the novel temperature dependence of junction performance for mid-wavelength HgCdTe detectors. The n-type region is formed by B+ ion implantation on Hg-vacancy-doped p-type HgCdTe. The opto-electrical properties of junction under different temperatures are characterized by laser beam induced current (LBIC) microscope. The physical mechanism of temperature on junction transformation is elaborated and demonstrated using numerical simulations.

The results show that Hg-interstitial diffusion, temperature activated defects, and leakage current mechanism jointly lead to the p-n junction transformation depended on temperature, and wider band gap compared with the long-wave HgCdTe photodiode may correlate with the disappearance of junction extension effect.

9070-112, Session Posters-Tuesday

A fabrication and characterictics of microbolometer detectors using VOx/ZnO/VOx multilayer thin film processing

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In this work, a novel fabrication method for VOx-ZnO multilayers with mixed phase of the VO2 and V2O3 through the diffusion of oxygen by annealing at low temperature is presented. A stable sandwich structure of a VOx/ZnO/VOx multilayer was deposited at room temperature, through the oxygen gas flow rate, by RF sputtering system, and the mixed phase was formed through oxygen diffusion by annealing at O2 atmosphere. The results show that the single phase like multilayer formed by this process has a high TCR of more than -2.5%/K and low resistance of about 100 kohm at room temperature. XRD results for the as-deposited VOx/ZnO/VOx multilayer

and annealed at 300 oC in oxygen for 50 min are presented. XRD of as-deposited films was showed that V2O5 peak is dominant, and annealed films were VO2 peak. We could confirm the formation of mainly V2O5 phase and that the film was more crystallized into V2O5 by annealing at 300 oC in O2 from the XRD results. And, as the annealing temperature is increasing, a TCR value was increase, also we investigated with a different annealing time on the multilayer films. Silgle pixel bolometer detector was fabricated with bulk micromachining process, and then the device process results will be presented.

9070-113, Session Posters-Tuesday

Three-dimensional plasmonic metamaterial absorbers for high-performance wavelength selective uncooled infrared sensors

Shinpei Ogawa, Daisuke Fujisawa, Tomohiro Maegawa, Masashi Ueno, Mitsubishi Electric Corp. (Japan); Masafumi Kimata, Ritsumeikan Univ. (Japan)

A three-dimensional plasmonic metamaterial absorber (3D PMA) was investigated in order to enhance the performance of wavelength selective uncooled infrared (IR) sensors. 3D PMA is the two-dimensional array of the metal-based circle-shape microdisk connected to the metal plate with the pillar. All components of 3D PMA such as the microdisks, pillars, and metal plates are based on the thin plasmonic metal such as Au, Ag, Al and so on.

The absorption properties of 3D PMA were calculated by the Rigorous Coupled Wave Analysis. The thickness of each component can be reduced to be about twice the thickness of the skin-depth. The gap between the microdisks and the metal plate or the height of the pillar is such narrow as a few hundred nanometers. The plasmonic resonance of thin metal structure reduces thermal mass of IR absorbers.

The strong wavelength selective absorption was realized by the plasmonic resonance mode of the microdisks and the narrow-gap guided mode between the microdisk and the metal plate. The disturbance of the pillar for the both resonance can be negligible due to the plasmonic resonance on the edge of the microdisks. The absorption wavelength is defined mainly by the size of the microdisk regardless of the period. Therefore, the absorption wavelength is longer than the surface period, which leads to the small pixel size.

The small thermal mass and pixel size can be realized using 3D PMA structure. The results obtained here contribute to the high-performance uncooled IR sensors for a multi-color imaging.

9070-115, Session Posters-Tuesday

Mercury cadmium telluride implanted junction profile measurement and depth control

Songmin Zhou, Chun Lin, Yanfeng Wei, Zhenhua Ye, Haibin Li, Dan Liu, Ruijun Ding, Li He, Shanghai Institute of Technical Physics (China)

The junction formation is one of key techniques to fabricate the HgCdTe focal plane arrays (FPAs). The qualities of the junctions act one critical role to the HgCdTe FPAs performance. Parameters of the junction include the junction depth, doping species and levels, defects' concentration and so on. Usually, the junctions of planar HgCdTe FPAs are formed by ion implantation. The implantation processing will introduce damages into the pn junctions. The damages will increase the Schocley-Read recombination and trap assistant tunneling (TAT) probability, and eventually degrade the merit factor (R0A) and HgCdTe FPAs performances. Therefore, in order to prohibit the degeneration and improve the dark current characteristic, annealing process is applied to eliminate the implantation damages, and it would push the depletion of junction to a deeper place which has less damage and dislocations to avoid the influence of the damages. To identify the annealing effect, an efficient way is to measure the expansion of junction depth after annealing. However, it's inconvenient or imprecise to determine the junction depth on HgCdTe epilayer by traditional methods, like differential Hall method, C-V method and EBIC method.

In this work, a novel junction profile measurement method is proposed. A serial of junctions were fabricated by B+ implantation. Then a beveled bar which was about 10 millimeters long and several micrometres deep was formed by carefully controlled wet-etching. The remaining depth of n region changes from the full depth that is about 5.3 micrometers after ion implantation to zero depending on its lateral position and the slope of the etching bar.

I-V characteristic and Laser Beam Induced Current (LBIC) measurements were applied to determine the HgCdTe junction edge. The LBIC signal orrectification characteristic indicates the existence of a pn junction and vise versa. The junction depth is extracted from the position where the junction region disappears and the slope of the etching bar. The junction depth of intrinsic doped HgCdTe was measured, which is about 2.4 micrometers. A significant 0.4 micrometer thick n- region was observed. Moreover, junction depths of samples annealed at different experiment parameters were also investigated. The junction depths were linear with etching time at the same time. By this method, it's possible to measure the three dimensional profile of a planar pn junction.

9070-116, Session Posters-Tuesday

Advanced cryocoolers for high-end IR missile warning systems

Ilan Nachman, RICOR-Cryogenic & Vacuum Systems (Israel)

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 High end IR system, RICOR has met the challenge by developing new models capable of withstanding high ambient vibration conditions along with ambient temperature extremes in excess of 100°C, as typical for airborne jet fighter applications.

The development focused on cryocooler rigid structures approach and cold finger optimization in order to achieve high cooling capacity at high ambient, withstand the high level of vibrations and keep the challenged demand of detector Line of Sight.

In order to withstand such 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 a rigid structure of the 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 accelerated life demonstration test was performed at IDDCA level.

9070-117, Session Posters-Tuesday

Dark current measurement of Type-II superlattice infrared focal plane array detector

Michito Sakai, Haruyoshi Katayama, Junpei Murooka, Japan Aerospace Exploration Agency (Japan); Masafumi Kimata, Ritsumeikan Univ. (Japan); Yasuhiro Iguchi, Sumitomo Electric Industries, Ltd. (Japan)

We report a result of dark current measurement of Type-II superlattice (T2SL) infrared focal plane array (FPA). We used a 6um cutoff T2SL FPA introduced a readout integration circuit (ROIC) ISC0903 of FLIR Systems. In order to measure the dark current of FPA, we obtained images with different exposure time in a fully-closed cold shield of 77K. Using a temporal change rate of output and assuming a charge conversion efficiency of ROIC,

we obtain a dark current density of the FPA. The averaged dark current density of all pixels is 8?10-7 A/cm2 at the bias of -100mV. We also compare the result of a dark current measurement using a test element group (TEG), which is a single pixel detector, fabricated by the same process of FPA. The dark current density of TEG is 1?10-5 A/cm2 at the bias of -100mV which is higher than that of FPA. We discuss the discrepancy of the dark current density between FPA and TEG.

9070-118, Session Posters-Tuesday

Ferroelectric infrared detector with nano-SiO2 thermal isolation layer

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The thermal isolation layer plays a significant role in thermal infrared detector.At present, two kinds of structures for the thermal isolation, i.e. free standing micro-bridge structure and porous SiO2, were usually adopted for ferroelectric infrared detectors. The performance of the devices with these structures may be degraded or fail because of the mechanical stress mismatch between the multilayer or the high roughness of the porous SiO2 surface. As indicated by previous works, the thermal conductivity of nanostructure SiO2 may be one order smaller then that of bulk silica. In this paper the ferroelectric infrared detector with nanostructure SiO2 thermal isolation layer was reported. Pillar or slanted nanorod arrays of SiO2 are fabricated using Glancing Angle Deposition(GLAD) on Si substrate at room temperature, and the porosity higher than 74%. To obtain a smooth surface, an intermediate layer of SiO2 with porosity varying from 60% down to 0% is fabricated in between the SiO2 nanostructrued thin films and the lower Al electrode to further reduce the surface roughness. The surface roughness of the electrode is less than 22nm. Upon this, the prototype detector with P(VDF-TrFE) function layer and semitransparent NiCr top electrode with size 50*50um was made by the standard photolithography method. The processing temperature of the devices is lower than 200? which is comparable with the standard ROIC technique. The voltage responsivity of the device is up to 6500 V/W and 1500 V/W at 1Hz and 30Hz, respectively. The dielectric loss are both about 0.02 at 1Hz and 30Hz. The thermal conductivity of nano-SiO2 is 1.96E-4 W/m K, estimated from the frequency dependence of the voltage responsivity of the device. With such a small thermal conductance, the responsivity should be higher than the experimental result. The performance can be improved further by increasing the absorption of the radiation for the device, which is only about 13% at present.

9070-119, Session Posters-Tuesday

Adaptations of RICOR's tactical cryocoolers for space missions

Sergey V. Riabzev, RICOR-Cryogenic & Vacuum Systems (Israel)

Cryogenic cryocoolers represent a significant enabling technology for earth and space science enterprises. Many of the space instruments require cryogenic refrigeration to enable the use of advanced detectors to observe a wide range of phenomena.

Space programs such as Crism, Chemin, Messenger and others integrated RICOR's cryocoolers which adapted for space missions and passed flight acceptance tests, qualification thermal tests and life test.

The adaptation frame of work includes extensive cryocooler characterization and qualification test program to validate the cryocooler capability, thermal interfacing design with the detector, vibration export control, efficient heat dissipation in vacuum environment, robustness mounting design, compliance with outgassing requirements and strict performances screening.

The reliability of a crycooler at space environment analyzed in accordance with the space mission and the redundancy implications for set of cryocoolers work in parallel by thermal switching will be reviewed.

9070-120, Session Posters-Tuesday

Linear VOx-Au thin film bolometer array with simultaneous low-resistivity and high TCR

Evan M. Smith, Univ. of Central Florida (United States) and Plasmonics, Inc. (United States); James C. Ginn III, Andrew Warren, Christopher J. Long, David Shelton, Plasmonics, Inc. (United States); Robert E. Peale, Univ. of Central Florida (United States)

We present a design for a low-noise bolometer based on the temperature-dependent conductivity of VOx-Au film. Usual thin film bolometers compromise between low resistivity and high temperature coefficient of resistivity (TCR). Our vanadium oxide is alloyed with a small concentration of gold by co-sputtering, which potentially gives very low resistivity and very high TCR simultaneously. The film is implemented into an air bridge device having high thermal conductivity and small thermal time constant optimized for 30 to 60 Hz frame rates. The linear array functions as a low-power profile sensor with a modulated bias. For 1 V bias, we predict responsivity exceeding 1200 V/W. Johnson noise dominates, but thermal fluctuations also contribute, yet predicted NEP values are predicted as low as 1.0 x 10-11 W/Hz1/2. Preliminary device testing shows film resistivity below 2.5 ?-cm with TCR exceeding -2.0%. Preliminary measurements of NETD are reported.

9070-121, Session Posters-Tuesday

Recent improvements on mid-IR chalcogenide optical fibers

Christophe Lafond, Jean-François Couillard, Jean-Luc Delarosbil, Fernand Sylvain, CorActive High-Tech Inc. (Canada)

Fabrication process of arsenic-sulfide (AsS) and arsenic-selenide (AsSe) optical fibers has been improved to enhance the transmission in the mid-IR region.

Core and cladding glass rods precursors AsS and AsSe are synthesized in evacuated quartz ampoules by the melting-quenching method of highly purified raw materials. Typical attenuation spectrum of AsS or AsSe optical fibers shows impurities bands, such as SH, SeH, OH, which limit their operation and cause the increase of the attenuation loss in the mid-IR. Precursors purification methods and glass processing were improved to minimise those impurities bands. Regarding AsS fibers, long length optical fibers lower than 0.15 dB/m of attenuation around 2.7 microns were obtained with SH and OH impurities concentrations lower than 0.5 ppm and 10 ppb respectively. In the case of AsSe, the minimum of attenuation located at 6 microns is 0.2 dB/m and SeH concentration is lower than 0.5 ppm.

Efforts have been also made to improve the mechanical properties which are usually affected by several parameters such as drawing conditions or heterogeneous inclusions contained in the glass. The double-crucible method gives high quality core/clad interface and consequently increases the strength of the fiber. Inclusions consist mainly of carbon and silica particles. Those impurities enter the glass from initial precursors and are also formed by interaction with the apparatus material. Thanks to the process improvement, impurities particles are minimized and tensile strengths up to 45 kpsi and 55 kpsi are reached for AsSe and AsS fibers respectively.

9070-122, Session Posters-Tuesday

Determination of combustion products by passive FTIR optical remote sensing

Steven V. Plowman, Midac Corp. (United States)

A number of unique characteristics endow optical remote sensing techniques with a huge potential range of applications. The analysis requires no sampling apparatus and reports concentrations in near real time. Fourier transform infrared (FTIR) spectroscopy is in the vanguard of this range of techniques. While optimally an infrared source would be used in conjunction with an FTIR spectrometer, the only essential requirement is a body radiating mid infrared photons, that is to say a source of heat.

In most applications involving analysis of combustion products, this criterion is satisfied by the nature of the research. The use of a heat source in this manner is known as passive FTIR. Firefighters have used FTIR optical remote sensing during building fires, researchers use the method in the analysis of simulated fires, and groups as diverse as volcanologists and process control engineers have found utility in the technique

In this study scientists from MIDAC Corporation and Underwriters Laboratory monitored a test burn at the UL facility in Chicago, IL using passive FTIR. A proprietary polystyrene product was packed into cardboard boxes, which were then placed on wooden pallets, which were in turn arrayed in racks. Ignition was instigated at 4 points using blow torches. The temperature of the fire was modified with an automated sprinkler system. The spectrometer was mounted on a tripod without a telescope. The system was deployed on an observation balcony, and manually aligned by scientists using breathing apparatus. Data acquisition was controlled remotely. The window of the spectrometer was aimed at the seat of the fire. Many approaches exist to address the problem of producing absorbance spectra. The preferred approach of MIDAC applications scientists is to fabricate a background spectrum from the sample spectra themselves. Results show that passive FTIR is a suitable technique for the identification and quantification of many common combustion products.

9070-123, Session Posters-Tuesday

On the use of magnesium alloys for aerospace and defense mirrors

Kenneth S. Woodard, Lovell E. Comstock, Leonard G. Wamboldt, Joseph C. Crifasi, Corning NetOptix (United States)

Extreme lightweighting is becoming more of a demand in the aerospace and defense applications but they don't want the cost associated with beryllium or other exotic materials (SWAP-C). The current standard for producing cost effective, high performance mirrors is to diamond turn finish mirror blanks from wrought aluminum alloy (typically 6061-T6) stock. Lightweighting is achieved by machining away material to optimize the mirror stiffness versus figure. 80% material removal is about the limit for geometrical lightweighting while still retaining the structural integrity required for both the fabrication process and the operational environment. To reduce weight further typically requires material density and/or stiffness modulus improvements.

If the mirror geometry is already fixed and not fully stressed or there is room to take advantage powered relationship between section thickness and bending stiffness, then magnesium is an option to produce lighter weight mirrors than aluminum but without the cost of beryllium. This paper summarizes the status of diamond machined finishing and coating of magnesium alloys to produce cost effective, lightweight mirrors with high, broadband reflectivity and low scatter finish.

9070-124, Session Posters-Tuesday

ARINC 818 adds capabilities for high-speed video sensors and systems

Tim Keller, Great River Technology, Inc. (United States)

ARINC 818, titled Avionics Digital Video Bus, is the standard for cockpit video that has gained wide acceptance in both the commercial and military cockpits including the Boeing 787, the A350XWB, the A400M, the KC-46A and many others. Initially conceived of for cockpit displays, ARINC 818 is now propagating into high-speed sensors, such as infrared and optical cameras due to its high-bandwidth and high reliability.

The ARINC 818 specification that was initially release in the 2006 and has recently undergone a major update that will enhance its applicability as a high speed sensor interface. The ARINC 818-2 specification was approved in November 2013.

The revisions to the specification include: video switching, stereo and 3-D provisions, color sequential implementations, regions of interest, data-only transmissions, multi-channel implementations, bi-directional communication, higher link rates to 32Gbps, synchronization signals, options for high-speed coax interfaces and optical interface details. The additions to the specification are especially appealing for high-bandwidth, multi sensor systems that have issues with throughput bottlenecks and SWAP concerns. ARINC 818 is implemented on either copper of fiber high speed physical layers, and allows for time multiplexing multiple sensors onto a single link.

This paper discusses each of the new capabilities in the ARINC 818-2 specification and the benefits for ISR and countermeasures implementations.

9070-125, Session Posters-Tuesday

Thermomechancial characterization in a radiant energy imager using null switching

Javaneh Boroumand Azad, Imen Rezadad, Evan M. Smith, Robert E. Peale, Univ. of Central Florida (United States)

We present the analysis of thermomechanical noise for a MEMs-based infrared detector using null switching (NS) based on US patent No. 7977635. Unlike most detectors, which transduce IR to a change in resistance or capacitance, this detector transduces incident radiation to a change in the duty cycle of a repetitively closing switch. Hence, in the NS detector, signal is determined by the time that the switch closes. The uncertainty in the time of contact depends only on noise amplitude, not noise frequency. Thermomechanical noise is estimated using the equipartition theorem, giving a maximum rms vibrational amplitude of 45 pm for the fabricated cantilever switch at its natural frequency. This gives a worst case timing uncertainty of 700 ns and an NEP of 2 pW/Sqrt[Hz].

9070-126, Session Posters-Tuesday

Multistep plasma etching process for the development of highly detective InSb mid-IR sensor arrays

Chulkyun Seok, Seoul National Univ. (Korea, Republic of); Minkyung Choi, Ewha Woman's Univ. (Korea, Republic of); Jinwook Jung, Sehun Park, Seoul National Univ. (Korea, Republic of); In-Sang Yang, Ewha Woman's Univ. (Korea, Republic of); Yongjo Park, Advanced Institutes of Convergence Technology (Korea, Republic of); Euijoon Yoon, Seoul National Univ. (Korea, Republic of)

Indium-antimonide (InSb) is the most popular material for a detector in the 3-5 μm range for mid-infrared (mid-IR) detecting system. Especially, it has a great importance in defense and sensing area due to a wide range of applications in military devices such as missile chasing system. InSb photodetectors with p-n junctions formed by epitaxial growth with in-situ doping show the lower dark current and the higher operating temperature (100K) compared to the conventional InSb diodes made by ion implantation. For the fabrication of a device using InSb epitaxial layer, a plasma etching process is essential and the development of optimized etching process is one of the most important issues in order to fabricate highly sensitive InSb mid-IR sensor arrays.

In the first step of this work, to evaluate the suitability of conventional etching methods, ion beam etching (IBE) with CH4/H2/Ar gas mixture, Cl2/Ar gas mixture, Ar gas were investigated relatively. In the case of IBE with CH4/H2/Ar and Cl2/Ar gas mixture, by-products such as carbide and chloride were formed on the etched surface. In the case of Ar IBE, ions with high energy induced structural damages near the bombarded surface. To overcome the limitation of conventional techniques, we developed the multi-step plasma etching process for InSb using a gas mixture of Ar and N2. Combining two method, the multi-step plasma etching process was sequentially performed at pure Ar, Ar:N2=1:1, Ar:N2=1:2, and pure N2 ambient. When we gradually increased the amount of N2 gas flow during etching process, RMS roughness decreased from 1.9 to 0.4 nm. Moreover FWHM of LO peak (191 cm-1) in Raman spectra decreased from 7.11 to 5.46 and the intensity ratio of ITO/ILO also decreased from 0.14 to 0.07. These results indicate that multi-step plasma etching process is more effective in reducing the surface damage induced by ion-etching than that of conventional methods. Moreover, the thin-nitride layer on the etched InSb surface induced by N2 reactive ions resulted in passivation of dangling bonds. As a result, the product of resistance and area (R0A) enhanced from 2x103 to 9.3x103 ohm cm2. It represents that detectivity (D*) can be drastically enhanced by using multi-step etching process.

9070-127, Session Posters-Tuesday

Mid-wavelength infrared focal plane arrays based on type-II InAs/GaSb superlattice

Yanqiu Lv, Junjie Si, Luoyang Optoelectro Technology Development Ctr. (China)

A mid-wavelength 128*128 infrared focal plane arrays based on InAs/GaSb type-II superlattice was presented in this work. Superlattce materials were grown on GaSb substrates using MBE technology. Absorber structure for mid-wavelength detcetor was designed to be 8ML (InAs) / 8ML (GaSb). The pixel of the detector had a conventional PIN structure with a size of 50um *50 um. The device fabrication process consisted of mesa etching, side-wall passivation, metallization and flip-chip hybridization with readout integrated circuit (ROIC). The dark current I-V curve, responsivity spectra and blackbody current responsivity were measured at 77 K. The detector had a cut-off wavelength of 5.0um, and a peak detectivity more than 10^11 cmHz^1/2W^-1. Concept proof of infrared imaging was also demonsrated with the focal plane array at liguid nitrogen temperature.

9070-128, Session Posters-Tuesday

Vanadium oxide thin film with improved sheet resistance uniformity

Francis Genereux, Francis Provençal, Bruno Tremblay, Marc-André Boucher, Christine Alain, INO (Canada)

Resistance uniformity is playing a key role in the development of large, high resolution uncooled microbolometer arrays. With worsening resistance uniformity, gain and offset variations increase and therefore the dynamic range is reduced. Although several approaches have been proposed to compensate for gain and offset simultaneously, they all either decrease the SNR or increase the complexity of the chip. In addition, they are generally barely compatible with TEC-less operation. Therefore, improvement of the resistance uniformity is often the most efficient way to address this issue.

It has been recently argued that amorphous silicon-based microbolometers are more suitable than VOx based microbolometers for the microfabrication of large arrays due its inherently superior resistance uniformity. In addition, the resistivity of amorphous silicon could be modeled by Arrhenius' equation which significantly eases the computation of the correction table for TEC-less operation.

In this paper, we show that a sheet resistance uniformity better than 2.5% could be achieved over a wafer by fine tuning the deposition process. This produces dies with resistance uniformity less than 1%, which is comparable with the value reported for amorphous silicon-based microbolometers. In addition, we show that the resistivity can be modeled by Arrhenius' equation with a regression coefficient of 0.995.

9070-129, Session Posters-Tuesday

Implementation of high-dynamic range pixel architecture for SWIR applications

Melik Yazici, Huseyin Kayahan, Omer Ceylan, Sohaib S. Afridi, Atia Shafique, Yasar Gurbuz, Sabanci Univ. (Turkey)

This paper presents novel unit cell architecture for short wave infrared (SWIR) imaging applications. It has two input stages which are CTIA and SFD covering for both respectively low and high light, levels and automatic input stage selection circuitry that chooses best input stage. In order to select best input stage 2 step integration scheme is used. In the first very short integration charge is stored to determine which input stage will be used according to reference level, second integration is normal integration. Along with analog information, 1 bit digital information that contains which input stage is provided from cell. This information can be used for non-uniformity corrections. CTIA uses small capacitor in order to improve noise performance in low light levels; SFD uses moderate size capacitor for high light levels. User can select 2 modes for FPA manual and automatic mode. In manual mode, user can set CTIA or SFD for all pixels according to user needs. In automatic mode, each pixel selects input stage itself according to light level. Light level threshold can be adjusted with reference voltage. Automatic input stage selection for each pixel brings high SNR level and low noise along with highest possible dynamic range for SWIR imaging applications. CMOS 0.18um technology is used to realize unit cell. In the architecture of unit cell, circuit level techniques are used to optimize layout size. CTIA is designed as differential cascode amplifier. Differential amplifier can be used as comparator for input stage selection. Output of differential amplifier is connected to latch to store selected input stage information. Single pixel is fabricated and measurement results are provided along with simulation results.

9070-130, Session Posters-Tuesday

Using quantum filters as edge detectors in infrared images

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Some new filters inspired in quantum models are used as edge detectors in infrared images. In this case, Bessel, Hermite and Morse filters will be applied to detect edges and fibrillar structures in infrared images. The edge detectors will be built by the Laplacian of the mentioned quantum filters. Furthermore, using curvature operators, curvature detectors and amplifiers of contrast will be constructed to analyze infrared images.

The quantum filter prototyping will be done using computer algebra software, specifically Maple and its package, ImageTools. The quantum filters will be applied to infrared images using the technique of convolutions and blurred derivatives. It is expected that designed quantum filters will be useful for analysis and processing of infrared images. As future investigations, we propose to design plugins with the quantum filters that can be incorporated into the program ImageJ, which will facilitate the use of the quantum filters for the infrared image processing.

9070-131, Session Posters-Tuesday

Lightweight ZERODUR: a cost-effective thermally stable approach to both large and small spaceborne telescopes

Tony Hull, The Univ. of New Mexico (United States); Thomas Westerhoff, SCHOTT AG (Germany)

ZERODUR®, known as the "gold standard" mirror material for systems which require dimensional stability in the presence of gradients and transients, is now available lightweighted to the 85% to 90% level for high performance spaceborne telescopes. The technical approach to making these primary mirrors is the same, whether the aperture is less than 0.3m to larger than 4m. Since each mirror blank is made from a single monolithic billet of near zero expansion, isotropic and homogeneous ZERODUR® material, the resulting mirror is very stable over a wide range of scenes and orbits. Such telescopes can accommodate internal thermal design challenges of sensors addressing both non-thermal (UV, visible, low light level TV, NIR, SWIR, and mm) as well as thermal imaging systems (MWIR and LWIR), and deliver optimal performance. We will discuss this technology, and present actual examples of 0.3m and 1.2m mirrors recently built by SCHOTT. The method used to manufacture the lightweight substrate allows for remarkably attractive costs and lead times, low risk and is relevant to present and future spaceborne sensor trades.

9070-132, Session Posters-Tuesday

Theoretical modelling of LWIR nBn HgCdTe photodetector

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The nBn structure with an electron barrier sandwiched by n-type cap and absorber layers is predicted to suppress the Shockley-Read-Hall (SRH) generation-recombination processes and surface leakage. The MCT nBn structure has been studied by several groups to implement high operating temperature (HOT) device.

In this report, the numerical analysis of the Hg1-xCdxTe nBn device in LWIR region (λc=10μm) is performed with Crosslight APSYS. The detector performance characterized by dark current, photo current and detectivity is optimized by adjusting structural parameters such as Cd component and doping of each layer under various biases. Among the parameters, the trade-off between ΔEc and ΔEv is most intensively affected by Cd component of the barrier which was modified carefully and accomplished firstly. Furthermore, the effect of the trap density and trap energy level on the device performance is also investigated especially according to the processing techniques.

At 110K, the optimized detectivity of the LWIR MCT nBn device reaches 7.5?10^10 cmHz1/2/W in this report, better than that of the DLPH device (7.6?10^10 cmHz1/2/W). The novel nBn HgCdTe structure is potentially valuable in LWIR region since the controllable p-doping issue is circumvented and passivation precess is simplified.

9070-133, Session Posters-Tuesday

A 4-channel mixed-signal ASIC for analog ROICs and FPAs

Selim Eminoglu, Murat Isikhan, Nusret Bayhan, S. Tuncer Soyer, Serhat Kocak, Cem Yalcin, Mikro-Tasarim (Turkey)

No Abstract Available

9070-134, Session PS2

COUGAR: A liquid nitrogen cooled InGaAs camera for astronomy and electro-luminescence

Urbain Van Bogget, Vincent Vervenne, Rosa Maria Vinelli, Koen van der Zanden, Xenics NV (Belgium); Patrick J. Merken, Xenics NV (Belgium) and RMA (Belgium); Jan P. Vermeiren, Xenics NV (Belgium)

Xenics has designed and manufactured a 640*512 pixel, 20 μm pitch InGaAs array for electro-luminescence characterization and astronomical applications in the [0.9 – 1.55 μm] range. The FPA is mounted in a liquid nitrogen dewar and is operated by a low noise frontend electronics.

One of the biggest problem in designing sensors and cameras for electro-luminescence measurements is the auto-illumination of the detectors by the Readout circuit. Besides of proper shielding of the detectors, the ROIC shall be optimized for minimal electrical activity during the integration time of the very-weak signals coming from the circuit under test. For this reason a SFD architecture (like in the Hawaii sensor) was selected, resulting in a background limited performance of the detector.

The pixel has a (somewhat arbitrary) full well capacity of 400 000 e- and a sensitivity of 2.17 μV/e-.

The dark signal is app. 1 e-/pixel/sec and with the appropriate Fowler sampling the dark noise is below 5 e-rms.

The power consumption of the circuit is limited 2 mW, allowing more than 24 hours of operation on less than 1 l of liquid nitrogen. The FPA is equipped with 4 outputs (optional readout on one single channel) and is capable of achieving 3 frames per second. Due to the non-destructive readout it is possible to determine in a dynamic way the optimal integration time for each observation.

The Cougar camera is equipped with ultra-low noise power supply and bias lines; the electronics contain also a 24 bit AD converter to fully exploit the sensitivity of the FPA and the camera.

9070-136, Session PS2

HySpex ODIN-1024: a new high-resolution airborne HSI system

Søren Blaaberg, Trond Løke, Ivar Baarstad, Andrei Fridman, Norsk Elektro Optikk AS (Norway)

HySpex ODIN-1024 is a next generation state-of the-art airborne hyperspectral imaging system developed by Norsk Elektro Optikk AS. Near perfect coregistration between VNIR and SWIR is achieved by employing a novel common fore-optics design and a thermally stabilized housing. Its unique design and the use of state of the art MCT and sCMOS sensors provides the combination of high sensitivity and low noise, low spatial and spectral misregistration (smile and keystone) and a very high resolution (1024 pixels in the merged data products). In addition to its supreme data quality, HySpex ODIN-1024 includes real-time data processing functionalities such as real-time georeferencing of acquired images. It also features built-in onboard calibration system to monitor the stability of the instrument. The paper presents data and results from laboratory tests and characterizations, as well as results from airborne measurements.

9070-42, Session 8

Improved high-operating temperature MCT MWIR modules

Holger Lutz, Rainer Breiter, Heinrich Figgemeier, Timo Schallenberg, Wilhelm Schirmacher, Richard Wollrab, AIM INFRAROT-MODULE GmbH (Germany)

High operating temperature (HOT) IR-detectors are a key factor to size, weight and power (SWaP) reduced IR-systems. Such systems are essential to provide infantrymen with low-weight handheld systems with increased battery lifetimes or most compact clip-on weapon sights in combination with high electro-optical performance offered by cooled IR-technology.

AIM's MCT standard n-on-p technology with vacancy doping has been optimized over many years resulting in MWIR-detectors with excellent electro-optical performance up to operating temperatures of ~120K. In the last years the effort has been intensified to improve this standard technology by introducing extrinsic doping with Gold as an acceptor. As a consequence the dark current could considerably be suppressed and allow for operation at ~140K with good e/o performance. More detailed investigations showed that limitation for HOT > 140K is explained by consequences from rising dark current rather than from defective pixel level.

Recently, several crucial parameters were identified showing great promise to further optimization of HOT-performance. Among those, p-type concentration could successfully be reduced from the mid 10^16 / cm^3 to the lower 10^15/ cm^3 range.

Since AIM is one of the leading manufacturers of split linear cryocoolers, an increase in operating temperature will directly lead to IR-modules with improved SWaP characteristics by making use of the miniature members of its SX cooler family with single piston and balancer technology.

The paper will present recent progress in the development of HOT MWIR-detector arrays at AIM and show electro-optical performance data in comparison to focal plane arrays produced in the standard technology.

9070-43, Session 8

Ultra-low power HOT MCT grown by MOVPE for handheld applications

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In 2012 Selex ES demonstrated High Operating Temperature (HOT) MCT detectors with 5μm cut-off wavelength and f/4 aperture operating at temperatures above 200K. These detectors are grown by Metal Organic Vapour Phase Epitaxy (MOVPE) which enables fine control over the photo-diode structure. Since 2012 Selex has created two further generations of MOVPE HOT MCT, progressively improving operability and yield. This paper presents performance data for Selex's third generation of HOT MCT technology and describes the improvements to the diode design and materials processing that have enabled these advances. A parallel program has developed miniature Dewars with lower heatload and reduced manufacturing costs. When integrated with the latest generation of miniature linear cryo-engines the required cooler power is reduced to the region of 1W at temperatures of 200K. This paper will present example imagery from a detector operating with <1

Watt cooler input power. The combination of third generation HOT MCT, high efficiency Dewars and miniature linear coolers will allow a drastic reduction in SWAP-C for long range hand-held thermal imagers.

9070-44, Session 8

Large format 15μm pitch XBn detector

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Over the past few years, a new type of High Operating Temperature (HOT) photon detector has been developed at SCD, which operates in the blue part of the MWIR atmospheric window (3.4 - 4.2 μm). This window is generally more transparent than the red part of the MWIR window (4.4 - 4.9 μm), especially useful for mid and long range applications. The detector has an InAsSb active layer and is based on the new "XBn" device concept, which eliminates the Generation-Recombination dark current and enables operation at temperatures of 150K or higher, while maintaining excellent image quality. Such high operating temperatures reduce dramatically the cooling requirements of Focal Plane Array (FPA) detectors and allow for the use of a smaller closed-cycle Stirling cooler. As a result, the complete Integrated Detector Cooler Assembly (IDCA) has about 60% lower power consumption and a much longer lifetime compared with IDCAs based on standard InSb detectors and coolers operating at 77K.

In this work we present a new large format IDCA designed for 150K operation. The 15 μm pitch 1280?1024 FPA is based on SCD's XBn technology and digital Hercules ROIC. The FPA is housed in a robust Dewar and is integrated with Ricor's K508N Stirling cryo-cooler. The IDCA has a weight of ~750 gram and its power consumption at a frame rate of 100Hz is ~ 7 W. The Mean Time to Failure (MTTF) of the IDCA is more than 20,000 hours, greatly facilitating 24/7 operation.

We describe key electro-optical performance parameters of the new detector.

9070-45, Session 8

Lead salt TE-cooled imaging sensor development

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Progress on development of a lead salt thermoelectrically-cooled imaging sensor will be presented. The imaging sensor architecture has been integrated into field-ruggedized hardware, and supports the use of lead salt-based detector material, including lead selenide and lead sulfide. Images and video are from a lead selenide focal plane array on Silicon ROIC at temperatures approaching room temperature, and at high frame rates. Lead salt imagers uniquely possess three traits: (1) Sensitive operation at high temperatures above the typical 'cooled' sensor maximum (2) Photonic response which enables high frame rates faster than the bolometric, thermal response time (3) Capability to reliably fabricate 2D arrays from solution-deposition directly, i.e. monolithically, on Silicon. These lead salt imagers are less expensive to produce and operate compared to other IR imagers based on II-VI HgCdTe and III-V InGaAsSb, because they do not require UHV epitaxial growth nor hybrid assembly, and no cryo-engine is needed to maintain low thermal noise. Historically there have been challenges with lead salt non-uniformities and noise. Staring arrays of lead salt imagers are promising today because of ROIC technology advances and fabrication improvements. Non-uniformities have been addressed by on-FPA nonuniformity correction and 1/f noise has been mitigated with adjustable noise filtering without mechanical chopping. Finally, improved deposition process and measurement controls have enabled reliable fabrication of high-performance, lead salt, large format staring arrays on the surface of large Silicon ROIC wafers. The imaging array performance has achieved 30 mK at 2.5 millisecond integration time with f/1 lens in the 3-5 μm wavelength band with a two-stage TE cooler operating at 230 K. Operability of 99.6% is reproducibly available on 240 ? 320 arrays.

9070-46, Session 8

Type-II superlattices for HOT infrared imagers *(Invited Paper)*

Manijeh Razeghi, Northwestern Univ. (United States)

No Abstract Available

9070-47, Session 8

Molecular beam epitaxy grown GaSb-based IR photodetectors

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The GaSb-based family of materials and heterostructures provides rich bandgap engineering possibilities for a variety of infrared (IR) applications. Molecular beam epitaxy (MBE) has become the primary technology for the growth of mid-wave and long-wave IR photodetector structures on GaSb substrates up to 4 inch diameter as well as on GaAs substrates up to 6-in diameter. In particular, nBn barrier-type photodetectors have attracted significant interest due to suppression of dark currents and a straight-forward, reproducible structure design, and are progressing toward commercial manufacturing applications. Device architectures utilize the 6.1 Å GaSb-based alloys such as InAsSb absorber layers with AlGaAsSb barrier layers, where the barrier material has appropriate band alignment with the absorber to eliminate current blocking for photo generated carriers, thus reducing electron-related dark currents. Such photodetectors with bulk InAsSb absorbers were demonstrated at cutoff wavelengths in the 4.2~7.0 μm range. Alternative detector architectures, including strained superlattices, can push into the 7~11 μm range. Recently, InPSb-based alloy lattice-matched to GaSb has been evaluated as an nBn absorber material for short wave IR applications in the 2.8~3.2 μm range. In this paper, we will report our latest results on the MBE growth of GaSb-based photodetector structures covering the short-wave to long wave IR spectral range. Material properties based on AFM, XRD, cross-section TEM and low temperature PL characterization will be presented, as well as electrical data from large-area mesa diodes. We will also discuss the feasibility of integrating a short-wave photodetector with similar GaSb-based mid- and long-IR nBn devices on the same GaSb substrate.

9070-48, Session 8

Absorption characteristics of mid-wave infared strained layer superlattices

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The mid?wave infrared (MWIR) spectral range has presently become the spectral region of choice for forward looking infrared sensor systems on military aircraft due to the advantages of greater image contrast, enhanced diffraction?limited resolution, and lower cost focal plane arrays (FPAs) with high operability. Today's MWIR FPA technology is primarily based on matured semiconductor materials such as InSb and HgCdTe, however, the recently emerged MWIR type?II superlattice (T2SL) technology is of potential future interest. Although T2SL material development and device design efforts have advanced to the FPA stage, there are still some areas of basic material research that need to be investigated. In this work, the focus is on infrared absorption characteristics of T2SL structures based on both InAs/GaSb and InAs/InAsSb material systems. Optical constants are obtained by infrared transmission spectroscopy and variable angle spectroscopic ellipsometry, and the effects of various T2SL parameters (such as material, thickness, and doping) on these optical constants will be discussed. T2SL detectors have proven to be the next candidate for high operating temperature MWIR detectors due to acceptably low dark currents; however, to reach the quantum efficiency of InSb detectors, T2SL detectors should exhibit InSb?Like absorption characteristics.

9070-49, Session 8

Midwave infrared interband cascade photodetectors and focal plane arrays *(Invited Paper)*

Zhaobing Tian, Sebastian E. Godoy, Theodore Schuler-Sandy, Clark Kadlec, Erin Dughie, Ha Sul Kim, Sanjay Krishna, The Univ. of New Mexico (United States)

The Interband Cascade (IC) photodetector with InAs/Ga(In)Sb type-II superlattice (T2-SL) absorbers has many unique features. In such IC detector design, the T2-SL absorption region is sliced into multiple thinner absorbers, sandwiched between electron barriers and hole barriers, forming one stage, and multiple stages electrically connected in series. The asymmetric energy-band alignment and efficient carrier transport channel have enabled IC detectors to operate under (near) zero-bias. The large lifetime contrast and the great design flexibility make IC detectors very suitable for high temperature operations. Our effort has led to the demonstration of mid-IR single pixel device operating up to 450 K under zero-bias, and these devices have achieved superior electrical performance compared to MCT technology at higher operation temperatures. In this presentation, we will discuss the new developments of low-noise mid-IR IC photodetectors and their focal plane arrays. Device study about the influence of design on their optical and electrical performance will be discussed, and the most recent technical progress will also be reported. Support from AFRL and AFOSR is acknowledged.

9070-50, Session 9

Uncooled digital IRFPA-family with 17μm pixel-pitch based on amorphous silicon with massively parallel Sigma-Delta-ADC readout

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This paper presents the results of an advanced digital IRFPA-family developed by Fraunhofer-IMS. The IRFPA-family compromises the two different optical resolutions VGA (640 x 480 pixel) and QVGA (320 x 240 pixel) by using a pin-compatible detector board. The uncooled IRFPAs are designed for thermal imaging applications in the LWIR (8 .. 14μm) range with a full-frame frequency of 30 Hz and a high thermal sensitivity. The microbolometer with a pixel-pitch of 17μm consists of amorphous silicon as the sensing layer. By scaling and optimizing our previous microbolometer technology with a pixel-pitch of 25μm we enhance the thermal sensitivity of the microbolometer. The microbolometers are read out by a novel readout architecture which utilizes massively parallel on-chip Sigma-Delta-ADCs. This results in a direct digital conversion of the resistance change of the microbolometer induced by incident infrared radiation. To reduce production costs a chip-scale-package is used as vacuum package. This vacuum package consists of an IR-transparent window with antireflection coating and a soldering frame which is fixed by a wafer-to-chip process directly on top of the CMOS-substrate. The chip-scale-package is placed on a detector board by a chip-on-board technique. 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.

9070-51, Session 9

Latest improvements in μ-bolometer thin film packaging: paving the way for low-cost consumer applications

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Silicon based vacuum packaging is a key enabling technology for achieving affordable uncooled Infrared Focal Plane Arrays (IRFPA) required by the promising mass market that shows momentum for some extensive consumer applications, such as automotive driving assistance, smart presence localization, building management...

Among the various approaches studied worldwide, CEA, LETI in partnership with ULIS is committed in the development of a unique technology referred to as PLP (Pixel Level Packaging), where each bolometer pixel is sealed under vacuum, using a transparent thin film deposition on wafer which operates as an array of hermetic micro caps above the focal plane, each containing a single microbolometer.

In continuation of the PLP studies conducted so far for a regular 320 x 240 IRFPA, this paper emphasizes on the straightforward scalability of the technology which was successfully applied to smaller arrays, typically 80 x 80 pixels FPAs . The relevance of the technology regarding the two formats is discussed, considering both performance and cost issues. It is shown that the low fill factor of the PLP arrangement is not any more an issue if we consider small arrays preferably fitted for consumer applications. The discussion is mainly supported by the electro optic performance of the PLP based 80x80 demonstrator, which relevant figures are extensively presented in this publication.

9070-52, Session 9

A miniature low-cost LWIR camera with a 160x120 microbolometer FPA

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No Abstract Available

9070-53, Session 9

Evaluation of 1/f noise in prospective IR imaging thin films

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Vanadium oxide (VOx) and hydrogenated SixGe1-x systems are the two predominant thin film material systems used in resistive IR imaging. While thin films of VOx used in microbolometers have a resistivity typically between 0.1 and 1 ?-cm with a TCR between -1.4%/K to -2.4%/K, SixGe1-x:H thin films have a resistivity between 1,000-4,000 ?-cm with a TCR between -2.9%/K to 3.9%/K. Future devices may require higher TCR materials however higher TCR is loosely associated with higher resistivity and therefore high noise. This work compares 1/f noise of high resistivity VOx and Ge:H thin films having |TCR| > 3.6%/K. The high TCR thin films of VOx were found to be amorphous while, depending on the deposition conditions, the Ge:H thin films were either amorphous or nanocrystalline + amorphous. Evaluation of these VOx and Ge:H thin films indicates a superior process-property relation of 1/f noise in Ge:H thin films (with normalized Hooge parameter > 10^-20 cm^3) in comparison with thin films of VOx (normalized Hooge parameter > 10^-18 cm^3).

9070-54, Session 9

High-G launch testing of a low-cost un-cooled LWIR imager

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UAVs and smart munitions require low-cost IR sensors that fit within very small volumes, yet offer acceptable performance and landing/launch survivability. The LWIR band provides unique contrast for specific applications in both UAVs and smart munitions, with smart munitions presenting an additional challenge of high g-loads during launch. These high g-loads are not typically a design target of low-cost, un-cooled COTS IR sensors. This work addresses the challenges of adapting a COTS LWIR un-cooled FPA for launch survivability. The sensor will be modeled for mechanical stability and weaknesses identified. Modifications will be made to improve launch survivability and multiple units will be tested. Data will be presented on the optical performance (MTF) both before and after launches for multiple locations across the lens.

9070-55, Session 10

Nickel oxide and molybdenum oxide thin films for infrared-imaging prepared by biased target ion-beam deposition

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Vanadium oxide (VOx) thin films have been intensively used as sensing materials for microbolometers. VOx thin films have good bolometric properties such as low resistivity, high negative temperature coefficient of resistivity (TCR) and low 1/f noise. However, the processing controllability of VOx fabrication is difficult due to the multiple valence states of vanadium. In this study, metal oxides such as nickel oxide (NiOx) and molybdenum oxide (MoOx) thin films have been investigated as possible new microbolometer sensing materials with improved process controllability.

Nickel oxide and molybdenum oxide thin films were prepared by reactive sputtering of nickel and molybdenum metal targets in a biased target ion beam deposition tool. In this deposition system, the Ar+ ion energy (typically lower than 25 eV) and the target bias voltage can be independently controlled since ions are remotely generated. A residual gas analyzer (RGA) is used to precisely control the oxygen partial pressure. A real-time spectroscopic ellipsometry is used to monitor the evolution of microstructure and properties of deposited oxides during growth and post-deposition. The properties of deposited oxides thin films depend on processing parameters. The resistivity of NiOx thin films is in the range of 0.5 to approximately 100 ohm-cm with a TCR from -2%/K to -3.3%/K, where the resistivity of MoOx is between 3 and 2000 ohm-cm with TCR from -2.1%/K to -3.2%/K. We also report on the thermal stability of these deposited oxide thin films.

9070-56, Session 10

Polarization selective uncooled infrared sensor using an asymmetric two-dimensional plasmonic absorber

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A polarization selective uncooled infrared (IR) sensor has been developed using an asymmetric two-dimensional plasmonic absorber (2D PLA). 2D PLA is the Au-based 2D periodic dimple structure, where the photon can be manipulated by the spoof surface plasmon polariton. We have introduced

asymmetricity to 2D PLA in order to realize the polarization selective function. The numerical investigations demonstrate that 2D PLA with the ellipsoidal dimples (2D PLA-E) produces a polarization dependence on its absorption property due to the asymmetric shape of the ellipse.

A microelectromechanical systems-based uncooled IR sensor using a 2D PLA-E was fabricated through a complementary metal oxide semiconductor (CMOS) and a micromachining technique. 2D PLA-E was formed by Au layer sputtered on the SiO2 with the ellipsoidal holes. The Al layer was introduced to the backside of the 2D PLA-E in order to reflect the scattering light and prevent the absorption of SiO2. The measurement of the polarization dependence of responsivities shows that the responsivity was selectively enhanced depending on the polarization according to the asymmetricity of the ellipse.

The results obtained here are the direct evidence that a polarization selective uncooled IR sensor was realized simply by introducing asymmetricity to the surface structure of 2D PLA without any polarizers or optical resonant structures. It indicates that a pixel array where each pixel has a different detection polarization would be developed for polarimetric imaging by a standard CMOS and a micromachining technique.

9070-57, Session 10

Repulsive electrostatic force in MEMS cantilever IR sensors

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A MEMS cantilever designed for IR sensing that lifts from the surface by electrostatic repulsion and moves down due to IR absorption is described. The design is comprised of three conductors: a fixed buried plate, a fixed surface plate, and a moveable cantilever. All have the same square shape and are arranged parallel in a vertical stack with aligned edges. The surface plate and cantilever are biased at the same potential, and the buried plate is oppositely biased. This paper is focused on demonstration and optimization of electrostatic repulsion and its effect on device performance. Analytical calculation, using values of position-dependent coefficients of capacitance and electrostatic induction from finite-element numerical calculation, demonstrates the repulsive force on the cantilever and determines its magnitude. Finite element simulations of local fields confirm these results and give the distribution of the force across the cantilever. Size and motion effects have been studied. The electrostatic repulsion is compared with Casimir sticking forces. Individual MEMS cantilever devices of 100 micron dimension and also 3 by 3 arrays of 20 micron element dimensions were fabricated and repulsive forces signatures are observed experimentally by video microscopy and induced currents. Finally an optimum design is suggested to achieve highest repulsive force and best performance in IR detection. Advantages such as higher fill factor and easier fabrication can highlight the design among other featured MEMS devices with repulsive force. Possible applications include IR detection, switches, and micromirrors.

9070-58, Session 10

Design of a nanomachined pyroelectric detector for low-thermal conductance

Md Muztoba, Noureddine Melikechi, Mukti Rana, Delaware State Univ. (United States)

Uncooled infrared detectors are utilized in nightvision systems and scientific instruments such as spectrometers and radiometers. They provide good performance that has enabled systems to be developed which have reduced size, weight, and power consumption. Yet uncooled infrared detectors still have not reached their fundamental limits of performance. The evolution of lithography through direct write ebeam lithography, nanoimprinting, and deep ultraviolet lithography has enabled sub-100nm features to be patterned. Pyroelectric detector is a class of thermal detector in which the change in temperature causes the change in the spontaneous polarization in the sensing material. In this work, we report the design of uncooled pyroelectric detectors which utilized a nanometer sized truss to support the suspended detector. The design and performance of pyroelectric detectors have been conducted by simulating the structure with Intellisuite™ utilizing Finite Element Method (FEM). The simulated detectors had a spider web-like structure with each of the strut of spider web had a width of 100 nm. Ca modified lead titanate (PCT) was employed as the thermometer because of its high pyroelectric figure of merit. The pyroelectric detectors utilized Ni0.8Cr0.2 absorber, PCT sensing layer, Ti electrodes, Al2O3 structural layer to obtain low thermal conductance between the detector and Si substrate. Three different types of pyroelectric detectors were designed and analyzed. The first design had linear electrode and simple spider web support. The value of the thermal conductance of this detector was found to be 3.98E-8 W/K. The second design had a longer thermal path than the first one and had a thermal conductivity of 2.41E-8 W/K. The design was optimized for the best result by modifying the shape, dimension and thickness of various layers namely absorber, electrodes, sensing layer and struts. The thermal conductance of the third design was found to be as low as 4.57E-9 W/K which is significantly lower than previously reported values. This investigation pushed the performance of pyroelectric uncooled infrared detectors towards their fundamental limits by reducing the thermal conductance to a level where it is dominated by the radiative exchange. The highest calculated detectivity and reponsivity values were 1.15E10 cm Hz1/2/W and 4.9E7 V/W respectively with this value of thermal conductance.

9070-59, Session 11

A new digital readout integrated circuit (DROIC) with pixel parallel A/D conversion with reduced quantization noise

Huseyin Kayahan, Omer Ceylan, Melik Yazici, Yasar Gurbuz, Sabanci Univ. (Turkey)

A new pixel design has been proposed for PFM DROIC to reduce the quantization noise without further increasing the power consumption or pixel sizes. The method relies on a coarse quantization on charge domain which is followed by a fine quantization on time domain. In the first phase circuit operates as an ordinary PFM pixel and measures the stored charge by counting the number of resets. The remaining value, residue, is to be further measured for reduced quantization noise. This measurement is done on time domain in the proposed pixel. Counter is operated as a clocked counter while allowing the integration to continue until a final threshold crossing. Using a high speed clock enables very low quantization noise levels.

The proposed method has been proven on a prototype array of 32x32 with a pixel size of 30μm x 30μm. The process technology is 90nm CMOS. Quantization noise of 161e- together with 2.33Ge- charge handling capacity has been measured. Among the state of the art PFM DROICs, proposed architecture has the lowest FoM for power efficiency of 465fJ/LSB. The peak SNR is limited by the switching noise to 71dB and the dynamic range is 130dB. The operation of the proposed method for low power applications with moderate quantization noise levels is also discussed.

9070-60, Session 11

A high-dynamic range ROIC for SLS and other IR focal planes

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A high dynamic range ROIC featuring 16 bit Sigma-Delta data conversion has been developed for SLS and other IR Focal Planes. Sigma-Delta architecture enables tradeoff of sensitivity against power, foveal imaging, and dynamic target tracking.

In many applications where high dynamic range is desired, Sigma-Delta architectures have displaced most other architectures for analog to digital conversion (ADC). This is primarily because they have high performance/

power ratio while being low cost. Until now, it's been generally believed that Sigma-Delta ADCs are not useful in Read-Out ICs (ROICs), because they do not handle well the abrupt transitions resulting from multiplexing of uncorrelated pixels.

The key innovation behind this work is a serpentine read-out order in which the sampling of multiplexed pixels is limited to adjacent pixels, enabling use of high dynamic range, low power Sigma-Delta ADCs in ROICs. Optical effects, both lens limitations and diffraction limits attributable to the large wavelengths in the IR spectrum, result in spatial filtering which limits the differences seen by adjacent pixels. With serpentine read-out order, the spatial filtering effects, rather than ADC effects, set the limit in resolving adjacent pixels.

Using numerical methods, we emulated the effects of reading out sample images in this serpentine order and processed the resulting waveforms through a model of a Sigma-Delta ADC. Results were compared with the original image and the nature and details of the readout modified. Edge effects were significantly reduced by adding redundant serpentine readouts (each with its own ADC) which overlap and occur in opposite directions from those of the other serpentines. Averaging of the two digitized outputs on a pixel by pixel basis reduces edge effects, improves noise and SEU tolerance, and reduces inter-symbol interference. The redundant readouts also support an interleaved, double frame rate mode.

Two generations of ROIC are both designed for a hybridized imager where the detector and ROIC are mated in raw form, utilizing per pixel bump interconnect. The CTIA is implemented on the ROIC, aligned with the pixel locations on the detector. The present implementation divides the array into slices of 32 columns. Each slice processes a serpentine of pixels which winds across the columns before dropping down when the row is incremented, after which the readout is in the opposite direction. A single Sigma-Delta ADC is implemented for each slice. All of the multiplexing control and analog switching is located under the area dedicated to the pixel interconnects.

Generation one is designed for 30um pixel pitch, for SLS detectors at cryogenic temperatures. It is implemented in a 0.18um Tower-Jazz process. It interfaces with a 320 by 256 two color pixel array and supports frame rates to 240fps. At SNR of 12 bits, power consumption is 400mW, or 160nWatt/Pixel-FPS.

Generation two is designed for 12um pixel pitch at room temperatures. It is presently being implemented in the same 0.18um Tower-Jazz process. This version is designed for a 896 by 512 pixel array. It achieves its SNR of 16 bits with substantially lower 16nWatt/Pixel-FPS.

9070-61, Session 11

ROIC for uncooled microbolometer FPAs/ mixed-signal ASIC for analog ROICs and FPAs

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No Abstract Available

9070-62, Session 11

Implementation of pixel level digital TDI for scanning type LWIR FPAs

Omer Ceylan, Huseyin Kayahan, Melik Yazici, Atia Shafique, Sohaib S. Afridi, Yasar Gurbuz, Sabanci Univ. (Turkey)

Implementation of a CMOS readout integrated circuit (ROIC) based on pixel level digital time delay integration (TDI) for scanning type LWIR focal plane arrays (FPAs) is presented. TDI is implemented on 8 pixels with over sampling rate of 3. Analog signal integrated on integration capacitor is converted to digital domain in pixel, and digital data is transferred to TDI summation counters, where contributions of 8 pixels are added. Output data is 16 bit, where 8 bits are allocated for most significant bits and 8 bits for least significant bits. Control block of the ROIC, which is responsible of generating timing diagram for switches controlling the pixels and summation counters, is realized with VerilogHDL. Summation counters and parallel-to-serial converter to convert 16 bit parallel output data to single bit output are also realized with Verilog HDL. Synthesized verilog netlists are placed&routed and combined with analog under-pixel part of the design. Quantization noise of analog-to-digital conversion is less than 500e-. Since analog signal is converted to digital domain in-pixel, non-uniformities and inaccuracies due to analog signal routing over large chip area is eliminated. ROIC is fabricated with 0.18μm CMOS process and chip area is 10mm2. Post-layout simulation results of the implemented design and measurement results of fabricated chip are also presented. ROIC supports bi-directional scan, bypass operation, pixel select/deselect, automatic gain adjustment, and is programmable through serial or parallel interface. Input referred noise of ROIC is less than 750 rms electron, while power consumption is less than 20mW. ROIC is designed to perform both in room and cryogenic temperatures.

9070-63, Session 12

Technical considerations for designing low-cost, long-wave infrared objectives

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With the growth of uncooled infrared imaging in the consumer market, the balance between cost implications and performance criteria in the objective lens must be examined carefully. The increased availability of consumer-grade, long-wave infrared cameras is related to a decrease in military usage but it is also due to the decreasing costs of the cameras themselves. This has also driven up demand for low-cost, long-wave objectives that can resolve smaller pixels while maintaining high performance. Smaller pixels are traditionally associated with high cost objectives because of higher resolution requirements but, with careful consideration of all the requirements and proper selection of materials, costs can be moderated. This paper examines the cost/performance trade-off implications associated with optical and mechanical requirements of long-wave infrared objectives. Optical performance, f-number, field of view, distortion, focus range and thermal range all affect the cost of the objective. Because raw lens material cost is often the most expensive item in the construction, selection of the material as well as the shape of the lens while maintaining acceptable performance and cost targets were explored. As a result of these considerations, a low-cost, lightweight, well-performing objective was successfully designed, manufactured and tested.

9070-64, Session 12

Compact multispectral continuous zoom camera for colour and SWIR vision with integrated laser range finder

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In an electro-optical sensor suite for long range surveillance tasks the optics for the visible (450nm – 700nm) and the SWIR spectral wavelength range (900nm – 1700 nm) are combined with the receiver optics of an integrated laser range finder (LRF) . The incoming signal from the observed scene and the returned laser pulse are collected within the common entrance aperture of the optics. The common front part of the optics is a broadband corrected lens design from 450 – 1700nm wavelength range. The visible spectrum is splitted up by a dichroic beamsplitter and focused on a HDTV CMOS camera. The returned laser pulse is spatially separated from the scene signal by a special prism and focused on the laser receiver diode of the integrated LRF.

The achromatic lens design has a zoom factor 14 and F#2.6 in the visible path. In the SWIR path the F-number is adapted to the corresponding chip dimensions . The alignment of the LRF with respect to the SWIR camera line of sight can be controlled by adjustable integrated wedges.

The two images in the visible and the SWIR spectral range match in focus and FOV over the full zoom range between 2° and 22° HFOV. The SWIR camera has a resolution of 640x512 pixels. The HDTV camera provides a resolution of 1920x1080. The design and the performance parameters of the multispectral sensor suite is discussed.

9070-65, Session 12

Design challenges of variable magnification/variable object distance (VMODO) systems

Steven H. Vogel, Christopher C. Alexay, Troy A. Palmer, Naomi J. Pollica, StingRay Optics, LLC (United States)

There are many applications for optical zoom systems which operate through a range of working distances while at the same time requiring multiple magnification levels. The challenges associated with the design of these systems are greater than either a fixed focal length system or a continuous zoom system operating with an image at infinity. In this paper we will explore some of the optical and mechanical issues involved, the available tradeoffs between high optical performance and simple mechanical designs, and provide some of the approaches/solutions we found to these issues.

9070-66, Session 12

Folded path LWIR system for SWAP constrained platforms

Erin F. Fleet, Dale Linne von Berg, Michael L. Wilson, U.S. Naval Research Lab. (United States); Thomas G. Giallorenzi, DCS Corp. (United States); Barry M. Mathieu, Barry Design Associates, Inc. (United States)

Folded path reflection and catadioptric optics are of growing interest, especially in the long wave infrared (LWIR), due to continuing demands for reductions in imaging system size, weight and power (SWAP). We present the optical design and laboratory and field test data for a 50 mm focal length low f/# folded-path compact LWIR imaging system. The optical design uses 4 concentric aspheric mirrors, each of which is described by annular aspheric functions well suited to the folded path design space. The 4 mirrors are diamond turned onto two thin air-spaced aluminum plates which can be manually focused onto the uncooled LWIR microbolometer array detector. Stray light analysis will be presented to show how specialized internal baffling can be used to reduce stray light propagation through the folded path optical train. The system achieves near diffraction limited performance across the FOV with a 15 mm long optical train and a 5 mm back focal distance. The completed system is small enough to reside within a 3 inch diameter ball gimbal.

9070-67, Session 12

Implementation of a durable multispectral mirror coating for light-weighted ISR systems

Leonard G. Wamboldt, Corning NetOptix (United States); Robin M. Walton, Corning Inc. (United States); Jue Wang, Corning Specialty Materials, Inc. (United States); Gary A. Hart, Corning Tropel Corp. (United States); Jason Ballou, Timothy R. Soucy, Kenneth S. Woodard, Joseph C. Crifasi, Shane M. Stephens, Corning NetOptix (United States)

Corning Advanced Optics recently developed an enhanced durable silver coating on T6 6061-Al and other light weighted substrates like magnesium, silicon carbide, and graphite. This thin film stack consists of 5 layer types that when combined together result in a multiband mirror, highly reflective in Vis-SWIR-MWIR-LWIR bands, with enhanced chemical durability. In each layer type, methods and materials are used to process the layer so as to achieve the desired layer characteristics, which aid to enhance the durability performance of the stack. Any given layer may improve stack durability, but it is the combination of these layer types that result in this high level of performance. This paper will discuss the performance of this stack when exposed to salt fog, salt solubility, and extended humidity environments.

9070-68, Session 12

Fast, electrically tunable filters for hyperspectral imaging

V. Liberman, Lalitha Parameswaran, Christopher Gear, Alberto Cabral, Mordechai Rothschild, MIT Lincoln Lab. (United States)

No Abstract Available

9070-69, Session 13

Comparison of the thermal effects on LWIR optical designs utilizing different infrared optical materials *(Invited Paper)*

Alan Symmons, Raymond J. Pini, LightPath Technologies, Inc. (United States)

The growing demand for lower cost infrared sensors and cameras has focused attention on the need for low cost optics for the long wave and mid-wave infrared region. The thermal properties of chalcogenides provide benefits for optical and opto-mechanical designers for the athermalization of lens assemblies as compared to Germanium, Zinc Selenide and other more common infrared materials.

This investigation reviews typical infrared material's thermal performance and the effects of temperature on the optical performance of lens systems manufactured from various optical materials.

9070-70, Session 13

Optical glasses transparent in visible and thermal infrared region for multispectral imaging *(Invited Paper)*

Xiang-Hua Zhang, Laurent Calvez, Antoine Brehault, Univ. de Rennes 1 (France); Joël Rollin, Thales Angénieux S.A. (France); Philippe Adam, Délégation Générale pour l'Armement (France)

The fusion of the two complementary images, in visible/SWIR (short wave infrared) and in thermal infrared will lead to many new applications both in commercial and defense fields. As an example, for car driving assistance, visible/SWIR image is better for reading road indications and for detecting the presence of ice on the road. Thermal image is much better for seeing further and pedestrians in foggy condition and during the night. For defense applications, it is, for example, easier to move in the dark with intensified SWIR image and thermal imaging is indispensible to detect hidden hot target.

There are many optics operating either in the visible/SWIR region or in the far infrared region. Only two materials, known since long time, ZnS and ZnSe, can be considered for producing multispectral optics even they cover only partially these two spectral bands. The only way to produce complex asphero-diffractive optics, indispensable with these materials, is to use the expensive single point diamond tuning.

Chalcogenide glasses have been developed for thermal imaging and the advantages of these materials are associated with the possibility of fabricating complex and efficient optical elements with direct precision

molding. Commercial chalcogenide glasses are usually transparent up to 14 μm without significant visible transmission.

In this talk, we will present our last work on the development of chalcogenide-halide glasses with extensive transmission from 0.4 μm up to 12 μm, covering the entire visible range and the two atmospheric windows of 3-5 μm and 8-12 μm. The optical, mechanical and chemical properties will be presented. The possibility of molding optics, chromatic aberration correction, antireflection coating will be discussed.

9070-71, Session 13

Multispectral optics designs using expanded glass map *(Invited Paper)*

Shyam S. Bayya, Daniel J. Gibson, Vinh Q. Nguyen, Erin F. Fleet, Jas S. Sanghera, U.S. Naval Research Lab. (United States); Jay N. Vizgaitis, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Materials are needed for multiband IR imaging applications with transparency over a broad spectral range covering SWIR, MWIR and LWIR wavelength regions. The choices are often limited to zinc sulfide (ZnS), zinc selenide (ZnSe), Germanium (Ge) and a few commercially available IR glasses. Many of these materials have fixed refractive indices and cannot be tailored for dispersion compensation over a broad spectral region as is needed for multiband achromats.

We report new multispectral materials that transmit from 0.9 to > 12 μm in wavelength. These materials fill up the glass map for multispectral optics and vary in refractive index from 2.38 to 3.17. They show a large spread in dispersion (Abbe number) and offer some unique solutions for multispectral optics designs. Our results provide a wider selection of optical materials to enable simpler achromat designs. For example, we have developed glasses that have relatively high Abbe number in both the MWIR and LWIR regions, while our MILTRAN ceramic has low Abbe number in both regions. This makes for a very good combination of glasses and MILTRAN ceramic (analogous to crown and flint glasses in the visible) for MWIR + LWIR dual band imaging. These new NRL glasses have negative or very low positive dn/dT making it easier to athermalize the optical system. The advantages of new multi-spectral optics designs using the expanded material database will be presented at the conference.

9070-72, Session 13

Sulfur copolymers for infrared optical imaging *(Invited Paper)*

S. Namnabat, College of Optical Sciences, The Univ. of Arizona (United States); J. Griebel, College of Optical Sciences, Univ. of Arizona (United States); J. Pyun, The Univ. of Arizona (United States); R. A. Norwood, E. Dereniak, College of Optical Sciences, The Univ. of Arizona (United States)

The development of organic polymers with high refractive indices has been widely investigated, as a possible alternative to inorganic metal oxide, semiconductor, or chalcogenide-based materials for a variety of optical devices and components, such as waveguides, anti-reflective coatings, charge-coupled devices and fiber optic cables. In principle, organic-based polymers are attractive for these applications because of their light-weight, ease of processing, mechanical toughness, and facile chemical variation using commercially available precursors. However, one of the fundamental challenges associated with organic polymers is their generally low refractive indices in comparison to their inorganic counterparts. In this paper we report on the optical characterization of a new class of sulfur copolymers that are readily moldable, transparent above 500nm, possess high refractive index (n > 1.8) and take advantage of the low infrared absorption of S?S bonds for potential use in the mid-infrared at 3-5 microns. These materials are largely made from elemental sulfur by an inverse vulcanization process; in the current study we focus on the properties of a chemically stable, branched copolymer of poly(sulfur-random-1,3-diisopropenylbenzene) (poly(S-r-DIB). Copolymers with elemental sulfur content ranging from 50% to 80% by weight were studied by UV-VIS spectroscopy, FTIR, and prism coupling for refractive index measurement. Clear correlation between material composition and the optical properties was established, confirming that the high polarizability of the sulfur atom leads to high refractive index while also maintaining low optical loss. Applications of the materials for bulk optics and infrared components will also be discussed.

9070-73, Session 14

Layered chalcogenide glass structures for IR lenses *(Invited Paper)*

Daniel J. Gibson, Shyam S. Bayya, Jas S. Sanghera, Vinh Q. Nguyen, U.S. Naval Research Lab. (United States); Dean A. Scribner, Northrop Grumman Mission Systems (United States); Velimir M. Maksimovic, Northrop Grumman Information Systems (United States); John A. Gill, Northrop Grumman Corp. (United States); Allen Yi, The Ohio State Univ. (United States); John P. Deegan, Rochester Precision Optics, LLC (United States); Blair L. Unger, BLU Optics, LLC (United States)

A technique for fabricating novel infrared (IR) lenses can enable a reduction in the size and weight of IR imaging optics through the use of layered glass structures. These structures can range from having a few thick glass layers, mimicking cemented doublets and triplets, to having many thin glass layers approximating graded index (GRIN) lenses. The effectiveness of these structures relies on having materials with diversity in refractive index (large Δn) and dispersion and similar thermo-viscous behavior (common glass transition temperature, $\Delta Tg = 10°C$). A library of 10 chalcogenide glasses with broad IR transmission (NIR through LWIR bands) was developed to satisfy these criteria. The lens fabrication methodology, including glass design and synthesis, sheet fabrication, preform making, lens molding and surface finishing will be presented.

9070-74, Session 14

IR GRIN optics for SWaP sensitive platforms *(Invited Paper)*

Daniel J. Gibson, Shyam S. Bayya, Jas S. Sanghera, Erin F. Fleet, U.S. Naval Research Lab. (United States)

Graded index (GRIN) optics offer potential for both weight savings and increased performance but commercial availability has so far been limited to visible and NIR bands (wavelengths shorter than about 0.9 μm). NRL has developed novel diffusion-based IR-GRIN lens technology compatible with all IR wavebands (SWIR, MWIR and LWIR). IR-GRIN optics can enable compact multiband imagers for weight sensitive platforms including small UAVs and soldier handheld, helmet or weapon mounted cameras. The IR-GRIN lens technology, design space, testing methodology and performance advantages will be presented.

9070-76, Session 15

Optical cryocoolers outshine thermoelectrics *(Invited Paper)*

Richard I. Epstein, Thermodynamic Films (United States) and Univ. of New Mexico (United States); Mansoor Sheik-Bahae, The Univ. of New Mexico (United States); Markus P. Hehlen, Los Alamos National Lab. (United States)

Compact, vibration-free solid-state refrigerators, are ideal for cooling

infrared sensors. Such coolers could be integrated into infrared cameras, eliminating the need for liquid cryogens or bulky, noisy mechanical coolers. Currently, the dominant solid-state cooling technology is thermoelectric cooling, which uses the Peltier effect. Despite decades of effort, the lowest achievable temperature for multi-stage thermoelectric coolers (TECs) is around 170 K. Programs at ThermoDynamic Films, LLC, the University of New Mexico and Los Alamos National Laboratory have made important strides developing an entirely different solid-state cooling technology, optical refrigeration, which removes heat by anti-Stokes fluorescence. This approach has advanced to the stage where it now cools to much lower temperatures than TECs. Laboratory measurements have demonstrated optical refrigeration cooling from room temperature to 114 K. This talk will describe the physical principles and current status of optical refrigeration and our goals for the near future. One immediate goal is building lightweight, compact optical refrigerators that can be easily integrated with IR sensors. In parallel, we are developing improved cooling materials that can allow optical refrigeration to cool below the 80 K. The talk will also describe our longer-term goals and approaches for improving the cooling efficiency of optical refrigerators to exceed that of current generation of mechanical cryocoolers. In parallel, we are developing improved cooling materials that can allow optical refrigeration to cool below the 80 K. The talk will also describe our longer-term goals and approaches for improving the cooling efficiency of optical refrigerators to exceed that of current generation of mechanical cryocoolers.

9070-137, Session 15

Lanthanide-doped materials for solid state optical refrigeration *(Invited Paper)*

Markus P. Hehlen, Los Alamos National Lab. (United States); Mansoor Sheik-Bahae, The Univ. of New Mexico (United States); Seth D. Melgaard, The Univ. of New Mexico (United States) and Air Force Research Lab. (United States); Richard I. Epstein, The Univ. of New Mexico (United States) and ThermoDynamic Films, LLC (United States)

Optical refrigeration of solids is possible in some materials that exhibit anti-Stokes fluorescence. Glasses and crystals doped with lanthanide ions such as Yb3+ and Tm3+ have proven most successful in recent years, culminating in recent solid-state laser cooling to below 100 K from room temperature. The operating point of a solid-state optical refrigerator is a compromise between operating temperature and heat lift. The laser-cooling material plays a key role in this tradeoff, with the important factors being the absorbed laser power, the pump wavelength, the external quantum efficiency, and undesired background absorption by impurities. These material parameters will be discussed, and the latest laser-cooling results achieved with Yb3+-doped YLiF4 crystals will be reviewed. Transition-metal ion impurities limit the cooling performance as they can directly absorb pump light or act as acceptors in energy-transfer processes from Yb3+, producing parasitic heating within the laser-cooling material. Such impurities are often present at ppm levels in commercial materials. However, low ppt impurity levels are needed for efficient laser coolers, making purification of starting materials a necessity. Several methods for removing transition-metal impurities are discussed. Next-generation ultrapure fluoride crystals are expected to have 10x lower background absorption than current materials, enabling the higher Yb3+ concentrations needed for efficient pump light absorption. Such materials may be able to cool to near the boiling point of liquid nitrogen (77 K) or have heat lifts approaching 1 Watt at 100 K.

9070-78, Session 16

Adaptive vibration reduction on dual-opposed piston free displacer Stirling cooler

Roel Arts, Bram de Bruin, Daniel Willems, Garmt de Jonge, Tonny Benschop, Thales Cryogenics B.V. (Netherlands)

In a Stirling-type Pulse Tube cooler with a dual opposed piston compressor, the residual vibration exported by the cooler is primarily a result of residual imbalances between compressor halves.

Using an electronic feedback loop and driving compressor halves independently, the exported force from the compressor can be regulated to negligible levels. This has been demonstrated in a multitude of commercial applications as well as in space applications. However, in the tactical infrared market where Stirling coolers with a moving displacer are predominantly used, this technology has not seen widespread use.

In a novel application of adaptive vibration reduction, the residual exported forces resulting from the motion of the free moving displacer of a Stirling cold finger can be compensated, by using a linear dual opposed piston compressor with two independently driven pistons as an active balancer.

The used vibration reduction algorithm is fully adaptive, enabling effective suppression of exported vibrations independent of the operating conditions of the cooler such as orientation, ambient temperature, tip temperature and heat load.

A theoretical analysis of the first-harmonic suppression of the exported force due to the free moving displacer is provided, measurements are presented on different cooler types and orientations, and the effect of integration aspects - hard mount versus suspended mount – is discussed. It is shown that, with careful attention to integration aspects, adaptive vibration reduction enables Stirling coolers to be used in applications where vibration sensitivity was previously prohibitive for this technology.

The effect on exported vibration as well as power efficiency is discussed and compared between Stirling and Pulse Tube type coolers.

9070-79, Session 16

RICOR's cryocoolers development and optimization for HOT IR detectors

Amiram Katz, RICOR-Cryogenic & Vacuum Systems (Israel)

The world growth in research and development of High Operating Temperature IR detectors impels the development process and the optimization of "HOT" cryocoolers at RICOR.

The development emphasis on the "SWAP" configuration which is small size, low weight and low power consumption, in order to optimize IDDCA for future hand held thermal sights.

This paper will present optimization tests results performed on a "HOT" prototype cryocoolers at the FPA temperature range of 110 - 200K and also will review the development activities that will be implemented in order to minimize "Idle electronic and mechanical losses" hence minimizing the regulated power consumption.

As a result of the new approach of developed cryocoolers for HOT detectors, the improvement in the reliability is analyzed and will be reported in the paper.

9070-80, Session 16

Ruggedizing infrared integrated Dewar-detector-cooler assemblies for harsh environmental conditions

Alexander Veprik, Nataniel Ashush, Baruch Shlomovich, Yaakov Oppenheim, Yaakov Gridish, Ezra Kahanov, Alina Koifman, SCD Semiconductor Devices (Israel); Avi Tuito, SIBAT (Israel)

Cryogenically cooled infrared electro-optical payloads have to operate and survive frequent exposure to vibration and temperature extremes typical of the modern battlefield. This necessitates the development of special approaches to ruggedizing their sensitive components.

The ruggedizing requirement holds true specifically for Integrated Dewar-Detector-Cooler Assemblies, (IDDCA) the infrared Focal Plane Array (FPA) of which is supported by a thin-walled cold finger placed inside an

evacuated Dewar. Without sufficient ruggedizing of the FPA support, harsh environmental vibration may lead to an excitation of structural resonances that result in excessive FPA motion or even in mechanical fractures due to material overstressing. Furthermore, with standard solutions there may be insufficient heat sinking from IDDCA, especially at high environmental temperatures. This may lead to an increase of the reject temperature of the thermodynamic cycle negating the overall thermodynamic performance of the cryogenic cooler along with giving rise to parasitic radiation and conduction heat load.

The authors present their approach to the ruggedizing of IDDCA by the optimal combination of stiffening elements and wideband dynamic damping that are compatible with the requirements of the thermal and mechanical interfacing of the cold finger base. The outcomes of analytical predictions are supported by the results of full scale-testing.

9070-81, Session 16

AIM cryocooler developments for HOT detectors

Ingo Rühlich, Markus Mai, Carsten Rosenhagen, Andreas Withopf, AIM INFRAROT-MODULE GmbH (Germany)

Significantly increased FPA temperatures for both Mid Wave and Long Wave IR detectors, i.e. HOT detectors, which have been developed in recent years are now leaving the development phase and are entering real application. HOT detectors allowing to push size weight and power (SWaP) of Integrated Detectors Cooler Assemblies (IDCA's) to a new level. Key component mainly driving achievable weight, volume and power consumption is the cryocooler.

AIM cryocooler developments are focused to compact, lightweight linear cryocoolers driven by compact and high efficient digital cooler drive electronics (DCE) to also achieve highest MTTF targets. This technology is using moving magnet driving mechanisms and dual or single piston compressors. Whereas SX030 which was presented at SPIE in 2012 consuming less 3 WDC to operate a typical IDCA at 140K, next smaller cooler SX020 is designed to provide sufficient cooling power at detector temperature above 160K. The cooler weight of less than 200g, a total compressor length of 60mm makes it an ideal solution for all applications with limited weight and power budget, like in handheld applications. For operating a typical 640x512, 15µm MW IR detector the power consumption will be less than 1.5WDC.

MTTF for the cooler will be in excess of 30,000h and thus achieving low maintenance cost also in 24/7 applications. The SX020 compressor is based on a single piston design with integrated passive balancer in a new design achieves very low exported vibration in the order of 100mN in the compressor axis.

AIM is using a modular approach, allowing the use of 5 different compressor types with the same type of Stirling expander. The 6mm expander with a total length of 74mm is now available in a new design that fits into standard dewar bores originally designed for rotary coolers. Also available is a 9mm coldfinger in both versions. In development is an ultra-short expander with around 35mm total length to achieve highest compactness.

Technical solutions and key performance data for AIM's HOT cryocoolers will be presented.

9070-82, Session 16

High-efficiency digital cooler electronics for aerospace applications

Thomas T. Luong, Lauren Shaw, J. Brian Murphy, Edgar A. Moody, Andrew L. Lisiecki, Michael J. Ellis, Carl S. Kirkconnell, Iris Technology Corp. (United States)

Closed-cycle cryogenic refrigerators, or cryocoolers, are an enabling technology for a wide range of aerospace applications, mostly related to infrared (IR) sensors. While the industry focus has tended to be on the mechanical cryocooler thermo mechanical unit (TMU) alone, implementation on a platform necessarily consists of the combination of the TMU and a mating set of command and control electronics. For some applications the cryocooler electronics (CCE) are technologically simple and low cost relative to the TMU, but this is not always the case. The relative cost and complexity of the CCE for a space-borne application can easily exceed that of the TMU, primarily due to the technical constraints and cost impacts introduced by the typical space radiation hardness and reliability requirements. High end tactical IR sensor applications also challenge the state of the art in cryocooler electronics, such as those for which temperature setpoint and frequency must be adjustable, or those where an informative telemetry set must be supported, etc. Generally speaking for both space and tactical applications, it is often the CCE that limits the rated lifetime and reliability of the cryocooler system.

A family of high end digital cryocooler electronics has been developed to address the widest possible range of high end aerospace infrared sensor applications. The presented electronics are readily scalable from 10W to 500W output capacity; experimental performance data for both a 25W and 150W version are presented. The combination of a FPGA-based controller and dual H-bridge motor drive architectures yields high efficiency (>92% typical) and precision temperature control (+/- 30 mK typical) for a wide range of mechanical cryocooler types and vendors. This paper focuses on recent testing with the AIM SX030, AIM SF100, and Thales LPT 9510 cryocoolers.

9070-83, Session 16

A linear drive cryocooler for ultra-small infrared sensor systems

Richard Rawlings, Graham Averitt, Jessica Aguilar, DRS Technologies, Inc. (United States)

In response to continuing requirements for smaller, lighter, and lower power cryocoolers for tactical IR applications, DRS Technologies has developed its smallest linear drive cooler for the micro-Integrated Dewar Cooler Assembly (µIDCA). The entire cooler/Dewar assembly occupies slightly more than 2 cubic inches in a rectangular form that measures about 1-inch by 1-inch by 2-inches.

The design goals and constraints are presented and the resulting design is discussed. Operating parameters and testing results are summarized.

In addition to the review of the uIDCA cryocooler, this paper presents a brief update of long-term reliability and life testing for a variety of DRS' linear drive cryocoolers. This testing program was initiated prior to 2000 and has demonstrated cooler lifetimes in excess of 50,000 hours.

9070-84, Session 16

Analysis of life demonstration test results and field data for RICOR's high-reliable cryocoolers

Racheli Moshe, RICOR-Cryogenic & Vacuum Systems (Israel)

The growing demand for EO applications that work around the clock 24hr/7days a week, such as in border surveillance systems, emphasizes the need for a highly reliable cryocooler having increased operational availability and decreased integrated system Life Cycle (ILS) cost. In order to meet this need, RICOR has developed linear and rotary cryocoolers technologies which meet this challenge.

Cryocoolers MTTF analyzed by theoretical reliability evaluation methods, demonstrated by normal and accelerated life demonstration tests at Cryocooler level and finally verified by field data analysis were derived from cryocoolers operating at the system level.

The paper will focus on the reliability evaluation models for different technologies, report and analyze life demonstration test data at different mission profiles and verify the results by fielded cryocoolers operating as a feedback to approve the theoretical assumptions and calculation models. In addition, it will review the system's end user needs and expectations from advanced high reliable cryocoolers.

9070-85, Session 17

Hemispherical curved monolithic cooled and uncooled infrared focal plane arrays for compact cameras

Kevin Tekaya, Manuel Fendler, Delphine Dumas, Commissariat à l'Énergie Atomique (France); Karim Inal, Elisabeth Massoni, Mines ParisTech (France); Guillaume Druart, ONERA (France); David Henry, Commissariat à l'Énergie Atomique (France)

InfraRed (IR) sensor systems like night vision goggles, missile approach warning systems and telescopes have an increasing interest in decreasing their size and weight. At the same time optical aberrations are always more difficult to optimize with larger Focal Plane Arrays (FPAs) and larger field of view. Both challenges can now take advantage of a new optical parameter thanks to flexible microelectronics technologies: the FPA spherical curvature. This bio-inspired approach can correct optical aberrations (e. g. field of view curvature, coma, etc.) and reduce the number of lenses in camera conception.

Firstly, a new process to curve thin monolithic devices has been applied to uncooled microbolometers FPAs. A functional 256x320 25µm pitch (roughly 1cm?) uncooled FPA has been thinned and curved. Its electrical response showed no degradation after our process (variation of less than 2.3% on the response). Then a two lenses camera with a curved FPA is designed and characterized in comparison with a two lenses camera with a flat FPA. Their Modulation Transfer Functions (MTFs) show clearly an improvement in terms of beams dispersion.

Secondly, a new process to fabricate monolithic cooled flip-chip MCT-IRCMOS FPAs was developed leading to the first spherical cooled IR FPA: a 256x320 30 µm pitch FPA (roughly 1 cm?), with a spherical bending radius of 550 mm. A standard opto-electrical characterization at 80 K of the imager shows no additional short circuit and no mean response alteration compared to a standard IRCMOS shown in reference. Noise is also studied with a black body between 20 and 30°C.

9070-86, Session 17

Mercury cadmium telluride focal plane array developments at Selex ES for astronomy and spectroscopy

Ian M. Baker, SELEX Galileo Infrared Ltd. (United Kingdom); Gert Finger, European Southern Observatory (Germany); Keith Barnes, SELEX Galileo Infrared Ltd. (United Kingdom)

Selex-ES in Southampton, UK, is developing advanced infrared detectors for space and astronomy applications. Large format arrays, up to 2k x 2k, for the near-infrared and short wavelength bands utilise MOVPE HgCdTe on low cost GaAs to achieve low dark current and near-ideal MTF. These arrays can use conventional or avalanche photodiode arrays (APDs). APDs are also applied to high frame-rate, single photon applications, such as that required for wavefront sensors, interferometry and imaging of transient events. Most recent research is based on a custom device called Saphira (320x256/24micron) and measurements have been performed by the European Southern Observatory (ESO) in low flux conditions. Saphira has 32 parallel outputs for 5 Kframes/s and non-destructive readout to enable 'down the slope' or Fowler sampling techniques. Using MOVPE APDs with an avalanche gain of 50x, an operating temperature of 85K and 10ms integration time, very few pixel defects are observed. The read noise with 8 Fowler sample pairs was measured to be 0.26 electrons.

9070-87, Session 17

Optimized MCT IR-modules for high-performance imaging applications

Rainer Breiter, Holger Lutz, Stefan Rutzinger, Timo Schallenberg, Joachim C. Wendler, Detlef Eich, Heinrich Figgemeier, Ingo Rühlich, AIM INFRAROT-MODULE GmbH (Germany)

In today's typical military operations situational awareness is a key element for mission success. In contrast to what is known from conventional warfare with typical targets such as tanks, asymmetric scenarios now dominate military operations. These scenarios require improved identification capabilities, for example the assessment of threat levels posed by personnel targets. Also, it is vital to identify and reliably distinguish between combatants, non-combatants and friendly forces. To satisfy these requirements, high-definition (HD) large format systems are well-suited due to their high spatial and thermal resolution combined with high contrast. Typical applications are sights for long range surveillance, targeting and reconnaissance platforms as well as rotorcraft pilotage sight systems.

In 2012 AIM presented first prototypes of megapixel detectors with 1280x1024 elements and 15µm pitch for both spectral bands MWIR and LWIR. The modular design allows integration of different cooler types, like AIM's split linear coolers SX095 or SX040 or rotary integral types depending whatever fits best to the application. Large format FPAs have been fabricated using liquid phase epitaxy (LPE) or molecular beam epitaxy (MBE) grown MCT.

To offer high resolution in a more compact configuration AIM started the development of a 1024x768 10µm pitch IR-module. Keeping electro/optical performance is achieved by a higher specific charge handling capacity of the readout circuit (ROIC) in a 0.18µm Si CMOS technology. The FPA size fits to a dewar cooler configuration used for 640x512 15µm pitch modules.

The paper will present the development status and performance of large format IR-modules at AIM with small pixel pitch integrated in compact dewar cooler configurations

9070-88, Session 17

Sofradir's recent improvements regarding the reliability and performance of HgCdTe IR detectors

Xavier Brenière, SOFRADIR (France)

Sofradir IR detectors are being deployed in a lengthening line of space applications (earth observation, atmospheric observation, scientific missions, etc...), and also in the whole range of tactical applications (portable cameras, missile seekers, airborne and naval systems, etc...).

Sofradir is taking advantage of these two areas. Firstly, space applications are developing new advances and technologies that can later be introduced in the production of IR detectors for tactical applications, thereby increasing their quality and reliability. In addition, Sofradir can better satisfy space application requirements for failure rates, as these can only be demonstrated with the large number of detectors manufactured, which tactical applications provide. As a result, this approach offers a continuous cycle for reliability of IR detectors, accelerating reliability growth in production, and at the same time meeting requirements for space applications.

This paper presents recent improvements introduced in production lines of HgCdTe detectors, that increase performances, image quality, and reliability.

9070-89, Session 17

Dual-band photon sorting plasmonic MIM metamaterial sensor

Young Uk Jung, The City College of New York (United States); Igor

Bendoym, National Science Foundation (United States); Andrii B. Golovin, David T. Crouse, The City College of New York (United States) and National Science Foundation (United States)

We propose a plasmonic metal-insulator-metal (MIM) metamaterial design for the sensing of two infrared wavelength bands. This structure can simultaneously capture light in the mid-wavelength infrared (MWIR) and long-wavelength infrared (LWIR). Our design is based on coupling of incident electromagnetic waves to a sub-wavelength plasmonic mode within a MIM metamaterial. Photon sorting can be performed such that light of a broad spectrum can be incident upon a surface that “splits” the light according to wavelength, sorting the light of different wavelengths to different areas of the MIM where it is then absorbed by the insulator. Two different structures described in this work are (1) Square-type structure which consists of absorbing insulator and metal on top being periodically arranged on the metal substrate and (2) Meander-type structure which consists of absorbing insulator and metal on top and being connected to form meander shape. Mercury Cadmium Telluride (HgCdTe) posts are used absorbing materials within the MIM structure to generate free carriers and allow for collection of the carrier charges. Most dual-wavelength or two-color IR detection systems are costly and vertically-stacked complicated semiconductor structure. However, the proposed models have compact designs and can detect polarized or arbitrary polarized incident waves and exhibit efficient light splitting and absorption for the IR spectral band. Structural and material properties, the electric field distributions and Poynting vector fields at the resonance frequencies are provided. Applications include thermal imaging, night vision systems, rifle sights, missile detection and discrimination, dual bandwidth optical filters, light trapping, and electromagnetically induced transparency.

9070-90, Session 17

Latest developments in the p-on-n architecture at DEFIR

Laurent Mollard, Pierre Castelein, Florent Rochette, CEA-LETI (France)

Since 2005, in the scope of “DEFIR”, the joint laboratory between CEA-LETI and SOFRADIR, p-on-n photodiodes and FPAs (Focal Plane Arrays) have been developed and optimised . This p-on-n architecture, obtained by As implantation into an In doped base layer, offered a significant decrease of the dark current compared to our n-on-p standard architecture. Following these developments, this p-on-n technology has been successfully transferred to SOFRADIR for industrial production . Results obtained on TV format, 15 μm pitch, showed that this first architecture has reached its maturity with excellent results in LWIR and MWIR.

In parallel, further developments and studies are still in progress at CEA-LETI in order to improve the photodiode performance and understanding of the physical mechanisms.

In this way, new p-on-n architectures have been studied on LPE (Liquid Phase Epitaxy) in the VLWIR spectral band. Using this new architecture, the transition temperature, where the dark current shifts from diffusion limited regime to another one, has been lowered by more than 10K. Extremely low dark current has been obtained, down to 50 e-/s/pixel.

Concerning MWIR and LWIR spectral bands, the reduction of production cost and the increase of resolution need smaller pixel pitches with larger format. In this way, first results have been obtained on test diodes with pixel pitch as low as 8 μm. The I(V) and R(V) plots illustrate the very good characteristic of our p-on-n diodes. These photodiodes present large reverse breakdown voltage, witnessing the quality of our device fabrication procedure.

In parallel of industrial production, CEA-LETI team have developed and characterized new p-on-n architecture and technological process which could open new ways for the next generation of p-on-n photodiodes.

9070-91, Session 17

Advances in MCT APDs

Michael D. Jack, RVS (United States)

No Abstract Available

9070-92, Session 18

The rationale for ultra-small pitch IR systems *(Invited Paper)*

Michael A. Kinch, DRS Sensors & Targeting Systems, Inc. (United States)

Large area high density vertically integrated (HDVIP) HgCdTe mid-wave infrared (MWIR) and long-wave infrared (LWIR) focal plane arrays (FPAs) are now available with a 5um pitch, and excellent performance with regard to noise equivalent temperature difference (NETD), pixel operability, and modulation transfer function (MTF). This analysis examines the potential benefits provided by these ultra-small pitch FPAs, not just on the resulting reduction in system size, weight, and power (SWAP), but also on the enabled improvement in system performance under extreme operating conditions, such as elevated operating temperatures. This potential performance strongly depends on the magnitude of dark currents associated with the chosen FPA detector architectures and materials technologies, and this analysis compares the limitations of prevailing HgCdTe photodiode architectures with today’s III-V barrier layer photoconductors, not only with regard to the current marketplace, but also with regard to achieving the ultimate end-goal of background and diffraction limited MWIR and LWIR FPA performance at room temperature. Such a goal also imposes severe requirements on many other aspects of IR FPA technology, such as excess 1/f noise, unit cell well capacity, and the development of pixel delineation and hybridization technologies to achieve a sufficiently adequate MTF for the ultra-small pitches involved. The challenges associated with these topics will be discussed.

9070-93, Session 18

HDVIP five-micron pitch HgCdTe focal plane arrays

John M. Armstrong, Mark R. Skokan, Michael A. Kinch, Joseph D. Luttmer, DRS Sensors & Targeting Systems, Inc. (United States)

Infrared detector pixel pitch has been decreasing, driven by interest in higher resolution, larger displays, and decreased cost. Previous generations of focal plane arrays (FPAs) were on 50, 40, 30, and 20μm pitch. 12μm pitch FPAs are now available. DRS Network and Imaging Systems has developed ultra-small 5μm pitch infrared detectors for the LWIR and MWIR bands as part of the DARPA AWARE Lambda Scale effort. This technology is a major advance in the state of the art for infrared imaging sensors. The pixel density of 4 million pixels/cm? enables the production of lower cost FPAs from HDTV resolution up to many millions of pixels.

DRS’ HgCdTe high-density vertically integrated photodetector (HDVIP™) pixel architecture was scaled down to 5μm pitch. LWIR and MWIR FPAs in the 1280x720 high-density format were built on a new read-out integrated circuit. The 5μm pitch FPAs use 82% less HgCdTe area to produce the same number of pixels at 12μm pitch. FPA operability above 99.7% was demonstrated for both HgCdTe cutoffs using a defect limit of twice the median RMS noise level. LWIR FPAs were packaged into f/1.0 cameras for demonstration and imagery was collected.

9070-94, Session 18

Getting small

Yann Reibel, Nicolas Ricard, Eric Mallet, Laurent Rubaldo, David Billon-Lanfrey, SOFRADIR (France); Nicolas Guérineau, Guillaume Druart, ONERA (France); Olivier Gravrand, CEA-LETI (France); Gérard L. Destéfanis, CEA-LETI (France) and ONERA (France)

Recent advances in miniaturization of IR imaging technology have led to a burgeoning market for mini thermal-imaging sensors.

Seen in this context our development on smaller pixel pitch has made much more compact products feasible. When this competitive advantage is mixed with smaller coolers made possible by HOT technology, we achieve valuable reductions in the size, weight and power of the overall package.

In the same time, we are moving to a global offer based on digital interfaces that provides our customers with simplification on the IR system design process while freeing up more space. Additionally we are also investigating new wafer level camera solution taking advantage of the progress in micro-optics.

This paper discusses recent developments on hot and small pixel pitch technologies as well as efforts made on compact packaging solution developed by SOFRADIR in collaboration with CEA-LETI and ONERA.

9070-95, Session 18

Benefits of oversampled small pixel Focal Plane Arrays (FPAs)

John T. Caulfield, Jerry Wilson, Cyan Systems (United States); Nibir K. Dhar, Defense Advanced Research Projects Agency (United States)

Recently, imaging systems using smaller sub diffraction sized pixels have shown good imaging results. There are known limits in undersampled and critically sampled sensors regarding resolution and aliasing. Oversampling the image using sub-diffraction size pixels offers much more than improved resolution, smaller FPAs, optics, and dewar systems. Oversampled pixels results in processing techniques for smaller pixels that enable a number of related systems benefits such as improved Instantaneous Field of View (IFOV), Noise Equivalent Power (NEP), False Alarm Rate, and detection range, as well as other system level benefits.

Cyan Systems has developed a small pixel ROIC/FPA that demonstrates these features. We will demonstrate that spatial oversampling can improve aliasing, sensitivity, and drive reductions in False Alarms through oversampled correlated processing. Oversampled pixels allow larger format FPAs and smaller optics, resulting in reductions in size, power, and weight. Oversampled IR sensors will also improve detection and acuity in turbulent and hazy conditions over larger pixel IR focal plane array sensors.

We will show quantitative data to illustrate the improvements in resolution, NEP, detection range, and false alarm suppression of the oversampled IR sensor as the temporal and spatial oversampling are increased. We will review the phenomena of reducing pixels size has on improving Noise Equivalent Power. We will show how smaller pixels have lower SNR, and how using temporal and spatial oversampling can compensate and effectively increase SNR lost with smaller pixels. We will quantify the limits of performance of Oversampling based on theory, and also with Monte Carlo type analysis using realistic parameters such as shot noise and thermal noise. We will review in detail the results of the Monte Carlo modeling of oversampling FPA. We will derive and demonstrate the theoretical limits of both temporal and spatial oversampling using both on and off Focal Plane processing that is required to realize good performance.

9070-96, Session 18

MTF issues in planar small pixel pitch quantum IR detectors

Olivier Gravrand, Alexandre Ferron, Florent Rochette, Laurent Mollard, CEA-LETI-Minatec (France); Jocelyn Berthoz, Laurent Rubaldo, SOFRADIR (France)

The actual trend in quantum IR detector development is the design of very small pixel pitch arrays. This is motivated by several aspects. First, it gives the ability to reach higher fabrication yield at a given FPA complexity to lower the cost of IR focal plan arrays. Moreover, it allows also higher formats for the same chip size, allowing the use of the same optics with a higher image resolution within a given system. From previously 30µm pitch, the standard pixel pitch is today 15µm and is expected to decrease to 12µm in the next few years. Furthermore, focal plane arrays (FPA) with pixel pitch as small as small as 10µm pitch has been demonstrated in the last few years.

Such ultra-small pixel pitches are very small compared to the typical length ruling the electrical characteristics of the absorbing materials, namely the minority carrier diffusion length. As an example for low doped N type HgCdTe or InSb material, this diffusion length is of the order of 30 to 50µm, ie 3 to 5 times the targeted pixel pitches. This might have strong consequences on the modulation transfert function (MTF) for planar structures, where the lateral extension of the photodiode is limited by diffusion. For such aspect ratios, the self-confinement of neighboring diodes may not be efficient enough to maintain optimal MTF. Therefore, this issue has to be addressed in order to take full benefits of the pixel pitch reduction in terms of image resolution.

This work aims at exploring the MTF evolution of HgCdTe and InSb FPAs decreasing the pixel pitch below 15µm. Both experimental measurements and finite element simulations will be used to discuss the different issues. Different scenarii will be compared, namely deep mesa etch between pixels, internal drift,...

9070-97, Session 19

Resonator-QWIPs and FPAs *(Invited Paper)*

Kwong-Kit Choi, U.S. Army Research Lab. (United States); Murzy D. Jhabvala, NASA Goddard Space Flight Ctr. (United States); Jason Sun, U.S. Army Research Lab. (United States); Christine A. Jhabvala, Augustyn Waczynski, NASA Goddard Space Flight Ctr. (United States); Kimberley Olver, U.S. Army Research Lab. (United States)

The quantum efficiency of QWIPs is difficult to predict and optimize. Recently, we have established a quantitative 3-dimensional electromagnetic model for QE computation. In this work, we used this model to design and optimize new detector structures. In one approach, we adjusted the detector volume to resonate strongly with the scattered light from the diffractive elements (DEs). The resulting intensified field increases the detector QE correspondingly. We tested this resonator-QWIP concept on five detector materials and obtained satisfactory agreements between theory and experiment. The observed single detector QE ranges from 15 to 71%, depending on the realized pixel geometry and the matching detector material. We processed one of the materials into hybridized FPAs and observed a QE of 30% with a conversion efficiency of 11%, in agreement with the theory. With these measured QE and CE, the NETD is projected to be 15 mK with 2.4 ms integration time under f/2 optics. The operability for NETD less than 25 mK is 99.57%. By using rings as DEs, the FPA spectral nonuniformity can also be minimized with an observed value of 3% in comparison with the 6% for gratings. With a proven EM model, we further designed different R-QWIPs for a wide range of applications, including high conversion efficiency detection, narrow band detection through a medium, narrow band detection at a gaseous medium, simultaneous two-color detection, sequential voltage tunable two-color detection, broadband detection at Landsat wavelengths, and detection of circularly polarized light. Experimental efforts are underway.

9070-98, Session 19

Comparison of two complementary surface plasmonic structures and their enhancement on infrared photodetectors

Guiru Gu, Xuejun Lu, Univ. of Massachusetts Lowell (United States)

Two complimentary Plasmonic structures, metallic disc array and 2 dimensional subwavlength hole array (2DSHA), are fabricated, measured, examined and analyzed. The excited SPPs by the two different plasmonic structures are visualized by the near field microscope. The metallic disc array and 2DSHA enhancement on QDIPs are also evaluated and compared. The 2DSHA give much higher peak photocurrent enhancement about 40 times, while the metallic disc array can provide 12 times with broad band enhancement. The cause of generating the different enhancement results is deeply analyzed. It's indicated that the QDIP performance enhancement depends on the nature of the excited field and interaction of the strong plasmonic fields with the QDs. Future suggestions are provided to improve the device enhancement based on the experimental and simulations results. The results provided in this work consolidate our efforts in bringing the innovative view of plasmonic research through two complementary plasmonic structures. This work can be more meaningful in the future potential applications of metallic particles.

9070-99, Session 19

Low-cost SWIR sensors: advancing the performance of ROIC-integrated colloidal quantum dot photodiode arrays

Ethan J. D. Klem, Jay S. Lewis, Chris W. Gregory, Dorota S. Temple, RTI International (United States); Nibir K. Dhar, Defense Advanced Research Projects Agency (United States); Priyalal S. Wijewarnasuriya, U.S. Army Research Lab. (United States)

RTI has developed a novel photodiode technology based on solution-processed PbS colloidal quantum dots (CQD) capable of providing low-cost, high performance detection across the Vis-SWIR spectral range. This technology has shown the potential to overcome the limitations of InGaAs FPAs that have held back the widespread adoption of high performance SWIR imaging systems. Although InGaAs-based focal plane arrays (FPAs) provide excellent detectivity and low noise they are characterized by high costs, limited visible-spectral response, and costly integration with Si ROIC devices. The inherent ease of fabrication of RTI's CQD photodiode technology makes it well suited for fabricating low cost, high yield detectors. RTI's CQD diodes can be processed at room temperature directly on ROICs without the need for the hybridization step required by InGaAs detectors. This reduces cost and leads to reduced pixel size and larger arrays.

We will present performance and yield data of diode arrays fabricated directly onto ROIC substrates and onto passive Si substrates. We will discuss recent advances in device architecture and processing leading to devices with room temperature dark currents of 2 nA/cm^2 and sensitivity from 350 nm to 1.7 μm. We will also show developments in advancing the responsivity of the detectors through the incorporation of a low-temperature transparent conducting oxide electrode. In addition, results evaluating reduced pixel size detectors from a previously demonstrated 30 x 40 μm down to 10 x 10 μm and 5 x 5 μm will be discussed.

This combination of high performance, dramatic cost reduction, and multi-band sensitivity is ideally suited to expand the use of SWIR imaging in current applications, as well as to address applications which require a multispectral sensitivity not met by existing technologies.

9070-100, Session 20

Low latency image processing

Derek Robison, BAE Systems (United States)

No Abstract Available

9070-101, Session 20

Digital CMOS focal plane array with on-chip multiple-accumulate units for low-latency image processing

Jeff Little, MIT (United States); Brian M. Tyrrell, Richard D'Onofrio, Christy Fernandez-Cull, MIT Lincoln Lab. (United States)

No Abstract Available

9070-102, Session 20

Hardware acceleration of Lucky-Region Fusion (LRF) algorithm for imaging

Christopher R. Jackson, Garrett A. Ejzak, Univ. of Delaware (United States); Mathieu Aubailly, Jony Jiang Liu, Gary W. Carhart, U.S. Army Research Lab. (United States)

"Lucky-region" fusion (LRF) is a synthetic imaging technique that has proven successful in enhancing the quality of images distorted by atmospheric turbulence. The LRF algorithm extracts sharp regions of an image obtained from a series of short exposure frames, and "fuses" the sharp regions into a final, improved image. In our previous research, the LRF algorithm had been implemented on a PC using a compiled programming language. However, the PC does not have sufficient processing power to handle real-time extraction, processing and reduction required when the LRF algorithm is applied not to single picture images but rather to real-time video from fast, high-resolution image sensors. This paper describes a hardware implementation of the LRF algorithm on a VIRTEX-7 field programmable gate array (FPGA) to achieve real-time video processing. The novelty in our approach is the creation of a "black box" LRF video processing system with a general camera link input, a user controller interface, and a DVI video output. We also describe a custom hardware simulation environment we have built to test our LRF implementation.

9070-103, Session 20

Smart pixel imaging with computational arrays (SPICA) *(Invited Paper)*

Christy Fernandez-Cull, Brian M. Tyrrell, Richard D'Onofrio, Megan Blackwell, Andrew Bolstad, Mike Kelly, Joseph H. Lin, Jeff Little, MIT Lincoln Lab. (United States)

Smart pixel imaging with computational arrays (SPICA) transfers image plane coding typically realized in the optical architecture to the focal plane array, thereby minimizing signal-to-noise losses associated with a binary-valued mask and inherent diffraction concerns. MIT Lincoln Laboratory has been developing both active and passive digital-pixel focal plane array (DFPA) devices for many years. In this work, we have leveraged legacy designs that have been modified with new features to produce a computational imaging array (CIA) with advanced per-pixel-processing capabilities. We describe the use of the CIA digital readout integrated circuit (DROIC) for on-chip background estimation and removal, image plane filtering, two-dimensional (2D) transient target tracking, and three-dimensional (3D) transient target estimation. In this work, we use a CIA DROIC capable of a 1 kHz global frame rate with up to 100 MHz

temporal multiplexing, where each pixel is modulated by a time-varying, pseudo-random, and duo-binary signal (+1,-1,0). This paper will focus on experimental results associated with 3D target estimation from per-pixel time-domain encoding with the CIA DROIC with limited loss of spatial resolution. We will compare structured and pseudo-random encoding strategies and employ linear inversion and non-linear total variation regularization algorithms to estimate a 3D (x,y,t) datacube from a 2D (x,y) temporally-encoded image. By transferring image plane coding to the ROIC and utilizing sophisticated processing, our CIA facilitates on-chip temporal super-resolution.

9070-104, Session 20

A bio-inspired IR sensor with on chip object computation

Paul L. McCarley, Air Force Research Lab. (United States); John T. Caulfield, Cyan Systems (United States)

No Abstract Available

9070-105, Session 21

Multispectral image fusion for face recognition at a distance

Fang Hua, Stephanie Schuckers, Clarkson Univ. (United States)

With the development of sensing technologies, image fusion of thermal and near IR images is becoming an active area of investigation for face recognition in challenging night operating environments. Each sensing modality has its own limitations, however, there is much utility in fusing these imagery together. In this paper, a new software-based registration and fusion of thermal and near infrared (IR) image data is proposed in order to illustrate the advantages and limitations of data fusion from multiple IR spectrums for face recognition in night operations.

There are 3 major contributions in this work: First, a new image registration method is proposed to spatially co-register thermal and near IR image pairs. Our rapid and accurate facial feature detectors for thermal and near IR images are helped to locate and align facial features for the registration.

Second, fusion of co-registered thermal and near IR image pairs is introduced and applied to generate one informative composite facial image. Fusing thermal and near infrared imaging data offers a viable means for improving the performance of face recognition techniques based on a single imaging modality. Pixel-based fusion in wavelet domain and feature-based fusion in eigenspace domain are investigated in this work and employed to adaptively select an optimum fusion strategy when dealing with varying resolution of images.

Third, performances of face recognition using thermal IR, near IR and thermal-near IR fused images are conducted with LBP, SIFT and PCA methods.

Experimental results show that the applied fusion method provides improvement of the spatial resolution and also improves face recognition system performance. Current night vision technologies are enabled through imaging in the active and passive cameras, especially the dual-mode active/passive cameras. This paper paves the way toward utilizing this dual-mode active/passive camera in face recognition at a distance.

9070-107, Session 21

Near-infrared face recognition utilizing open CV software

Louiza Sellami, Hau Ngo, U.S. Naval Academy (United States)

Commercially available hardware, freely available algorithms, and authors' developed software are synergized successfully to detect and recognize subjects in an environment without visible light. This project integrates three major components: an illumination device operating in near infrared (NIR) spectrum, a NIR capable camera and a software algorithm capable of performing image manipulation, facial detection and recognition. Focusing our efforts in the near infrared spectrum allows the low budget system to operate covertly while still allowing for accurate face recognition. In doing so a valuable function has been developed which presents potential benefits in future civilian and military security and surveillance operations.

9070-108, Session 21

Automated, long-range, night/day, active-SWIR face recognition system

Brian E. Lemoff, Robert B. Martin, Mikhail Sluch, Kristopher M. Kafka, Andrew Dolby, Robert V. Ice, West Virginia High Technology Consortium Foundation (United States)

Covert, long-range, night/day identification of stationary human subjects using face recognition has been previously demonstrated using the active-SWIR Tactical Imager for Night/Day Extended-Range Surveillance (TINDERS) system. TINDERS uses an invisible eye-safe, SWIR laser illuminator to produce high-quality facial imagery under conditions ranging from bright sunlight to total darkness. The recent addition of automation software to TINDERS has enabled the autonomous identification of moving subjects at distances greater than 100 m. Unlike typical cooperative, short range face recognition scenarios, where positive identification requires only a single face image, the SWIR wavelength, long distance, and uncontrolled conditions mean that positive identification requires fusing the face matching results from multiple captured images of a single subject. Automation software is required to initially detect a person, lock on and track the person as they move, and select video frames containing high-quality frontal face images for processing. Fusion algorithms are required to combine the matching results from multiple frames to produce a high-confidence match. These automation functions will be described, and results showing automated identification of moving subjects, night and day, at multiple distances will be presented.

Tuesday - Thursday 6 –8 May 2014

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9071-1, Session 1

Comparison of IRST systems by SNR

Charles Kim, Ron K. Meyer, Northrop Grumman Electronic Systems (United States)

Infrared (IR) cameras are widely used in search and track. IR search and track (IRST) systems primarily use one of two distinct spectral bands: mid-wave IR (MWIR) or long-wave IR (LWIR). Each of these bands have its own merit, yet system engineers often have to make a choice between them due to various constraints. Many have compared them in a number of ways. The comparison includes field data and analysis under various scenarios. Yet, it has been a challenge to make the right decision in choosing one band over the other band for a new scenario. Evaluating the performance of any system usually includes three areas: signal-to-noise ratio (SNR), resolution and clutter rejection. We focus on SNR. The SNR not only helps to make a decision for a new system, but also determines the range for detection. We have identified the common parameters for both bands. We have produced a general formula for comparison using noise equivalent differential temperature (NEDT) as a basis. We have shown examples under certain cases, each of which illustrates the evaluation and benefit of one band over the other. They provide an insight for system engineers to determine relative performance between the two bands in light of SNR.

9071-2, Session 1

Field of view selection for optimal airborne imaging sensor performance

Tristan M. Goss, P. Werner Barnard, ASELSAN Inc. (South Africa); Halidun Fildis, Mustafa Erbudak, Tolga Senger, Mehmet E. Alpman, ASELSAN Inc. (Turkey)

The choice of the Field of View (FOV) of imaging sensors used in airborne targeting applications has major impact on the overall performance of the system. Conducting a market survey from published data on sensors used in stabilized airborne targeting systems shows a trend of ever narrowing FOVs housed in smaller and lighter volumes. This approach promotes the ever increasing geometric resolution provided by narrower FOVs, while it seemingly ignores the influences the FOV selection has on the sensor's sensitivity, the effects of diffraction, the influences of sight line jitter and collectively the overall system performance.

This paper presents a trade-off methodology to select the optimal FOV for an imaging sensor that is limited in aperture diameter by mechanical constraints (such as space/volume available and window size) by balancing the influences FOV has on sensitivity and resolution and thereby optimizing the systems performance. The methodology may be applied to staring array based imaging sensors across all wavebands from visible/day cameras through to long wave infrared thermal imagers.

Some examples of sensor analysis applying the trade-off methodology are given that highlights the performance advantages that can be gained by maximizing the aperture diameters and choosing the optimal FOV for an imaging sensor used in airborne targeting applications.

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Some examples of sensor analysis applying the trade-off methodology that highlights the performance advantages that can be gained by maximizing the aperture diameters and choosing the optimal FOV for imaging sensor used in airborne targeting applications.

9071-3, Session 1

Thermal imager sources of nonuniformities: modeling of static and dynamic contributions during operations

Barbara Sozzi, Monica Olivieri, Claudio Giunti, Paolo Mariani, Stefano Zatti, Antonio Porta, SELEX Galileo S.p.A. (Italy)

Due to the fast-growing of cooled detector sensitivity in the last years, 10-20 mK temperature difference between adjacent objects can theoretically be discerned on the image if the calibration algorithm (NUC) is capable to take into account and compensate every spatial noise source. To predict how the NUC algorithm is strong in all working condition, the modeling of the flux impinging on the detector becomes a challenge to control and improve the quality of a properly calibrated image in all scene/ambient conditions including every source of spurious signal.

In literature there are lots of papers dealing with NU caused by pixel-to-pixel differences of detector parameters and by the difference between the reflection of the detector cold part and the housing at the operative temperature. These models don't explain the effects on the NUC results due to vignetting, dynamic sources out and inside the FOV, reflected contributions from hot spots inside the housing (for example thermal reference far of the optical path).

We propose a mathematical model in which:

1) detector and system (opto-mechanical configuration and scene) are considered separated and represented by two independent transfer functions

2) on every pixel of the array the amount of photonic signal coming from different spurious sources are considered to evaluate the effect on residual spatial noise due to dynamic operative conditions.

This article also contain simulation results showing how this model can be used to predict the amount of spatial noise.

9071-4, Session 1

Accounting for chromatic variations in system modeling and its influence on system performance

Jonathan G. Hixson, David P. Haefner, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

To accurately model the performance of today's vastly different array of visible cameras, ranging from the cheap low end cell-phone cameras to high end high definition surveillance sensors, the affect of using a broadband modulation transfer function (MTF) versus a spectrally varying MTF on target acquisition range performance predictions is explored. The monochromatic MTF is a spectral average across wavelength weighted by the sensors spectral sensitivity and scaled by the spectral behavior of the source. For reflective band sensors (400nm-700nm for this exercise), where there are significant variations in spectral shape of the reflected light, this spectral averaging can result in very different MTFs and therefore varying range performance. We explore the influence of this spectral averaging on performance utilizing NV-IPM v1.1 (Night Vision Integrated Performance Model). We examine the errors in range performance when a system is characterized with one illumination and the performance is quoted for another. We also show how systems with the same predicted performance for a particular illumination can have different performance under other spectral illuminations due to the different systems chromatic behavior. Our results summarize the accuracy of different assumptions to how a monochromatic MTF can be approximated and how the measurement conditions under which a system was characterized should be considered when modeling performance. In conclusion recommendations are made for

when a sensor designer needs to pay attention to the affects of chromatic variations on sensor range performance.

9071-5, Session 1

Method for quantifying image quality in push-broom hyperspectral cameras

Gudrun Hoeye, Trond Løke, Andrei Fridman, Norsk Elektro Optikk AS (Norway)

In this work we suggest a method for quantifying image quality in push-broom hyperspectral cameras. Important criteria for the image quality of such cameras are image sharpness as well as good spatial and spectral co-registration. Spatial misregistration – such as keystone and variations in the point-spread-function (PSF) across the spectral channels – distort the captured spectra. Similar types of errors occur in the spectral direction (smile effect and corresponding PSF variation). Quantifying these errors, as well as the image sharpness, would allow for evaluation and comparison of the performance of different hyperspectral imagers. However, how to measure and quantify these errors is currently not well defined.

Using the suggested method, we will show how misregistration errors and sharpness can be measured and quantified in a reliable and consistent way for different types of hyperspectral cameras. The mathematical framework will be described as well as the suggested measurement procedure. We will show how the measured camera performance can be presented graphically in an intuitive and easy to understand way – facilitating the comparison of different hyperspectral imagers. Finally, we will quantify the performance of an existing hyperspectral camera using this method.

The performance criteria established by this method could be useful guidelines when designing a new hyperspectral camera. The suggested method could become the standard for how to measure and quantify the image quality of push-broom cameras.

9071-6, Session 1

Direct optimization of LWIR system for maximized detection range and minimized SWAP

Robert M. Bates, FiveFocal LLC (United States)

With reductions in microbolometer size and cost, LWIR systems are increasingly being developed for unmanned aerial and ground vehicle applications with challenging size, weight, and power constraints. Past optimization of imaging systems toward the simultaneous objectives of improved stand-off detection and low size, weight, and power required an iterative, multi-disciplinary design process. Historically, the system design has been a very manual process which results in components that are unnecessarily over-engineered resulting in added size, weight, power, or cost to the system.

Through the development of system simulation and optimization software that incorporates the optical lens model with the target, sensor, display, and observer models, the end-to-end performance of the system can be optimized directly according to the probability of task performance using the standard targeting task performance (TTP) metric. With the subsystems incorporated into a model with optimization capabilities, trade-offs are more directly balanced across system components so that no component is over-designed for the objectives. Further, by incorporating a detailed optical model, the performance of the system can be balanced across field, providing critical insight into trade-offs with optical distortion, relative illumination, and MTF in meeting the system goals.

Full system optimization has been approached in the past by attempting to link disparate software packages together through a data interface. The authors have found this approach to be severely limited by the speed of the data connections. In the approach taken here, a complete software implementation was developed to bring all modeling aspects within one environment, enabling rapid system optimization. The optimized model is validated using NV-IPM as the standard.

In this paper, we demonstrate the direct optimization of the full LWIR system model including the optics, sensor, processing and display degrees of freedom with system level metrics including SWAP and detection range. The end result is a system with superior SWAP for a given detection range.

9071-7, Session 2

Performance trade space analysis for multifunction EO-IR systems

Keith A. Krapels, U.S. Army RDECOM CERDEC NVESD (United States); Ronald G. Driggers, St. Johns Optical Systems (United States)

As pixels have gotten smaller and focal plane array sizes larger, it may be practical to make EO-IR systems which are inherently multifunctional. A system intended to perform threat warning, pilotage imaging and target acquisition imaging would be a multifunctional system. This notional system could be panoramic or hemispheric with cameras covering segments of space simultaneously. It could save cost and weight over federated systems. However, can all of these disparate tasks be performed successfully by a single system? Or will the trade-offs compromise the potential savings?

Targeting sensors have typically been designed to create long range, high resolution imagery for detection and identification. The imagery is optimized to suppress the scene/clutter and maximize the target signature. Pilotage sensors have typically been wide field of view with unity magnification systems which maximize scene contrast to enable safe flight. Threat warning sensors are intended to detect unresolved (spatially or temporally) targets/events using algorithms to discriminate them from clutter or solar glint. The first two applications involve imagery for human operator consumption, while the third is processed by algorithms. With these disparate performance goals, there is a wide variety of competing metrics used to optimize these sensors – F-number, FOV/IFOV, frame rate, NETD, NEI, FAR, Probability of Identification, etc. This study is a theoretical look at how these performance parameters and system descriptors trade and their relative impacts.

9071-9, Session 2

Lab and field measurements to evaluate a differential polarimetric IR (DPIR) search sensor

Roger W. Thompson Jr., Van A. Hodgkin, Kevin R. Leonard, Bradley L. Preece, Keith A. Krapels, U.S. Army RDECOM CERDEC NVESD (United States)

Differential polarimetry has shown the ability to enhance target signatures by reducing background signatures, thus effectively increasing the signal-to-noise ratio on target. This method has mainly been done for resolved, high contrast targets. For ground-to-air search and tracking of small, slow, airborne targets, the target at range can be sub-pixel and hard to detect against the background sky. Given the unpolarized nature of the thermal emission of the background sky, it should be possible to use differential polarimetry to “filter out” the background, and thus enhance the ability of detecting sub-pixel targets. The first step in testing this hypothesis is to devise a set of surrogate sample targets and measure their polarimetric properties in the thermal IR in both the lab and the field. The goal of this paper is to determine whether or not it is feasible to use differential polarimetry to search, detect, and track small airborne objects.

9071-10, Session 2

Modeling the identification of helicopter landing hazards in degraded viewing conditions

Jeremy B. Brown, Eddie L. Jacobs, Zachary Tate, The Univ. of Memphis (United States)

Helicopter induced brownout can reduce visibility and hide potentially dangerous landing hazards. This research describes an approach to define a model for the probability of identifying a hazard, given image degradations of contrast and noise experienced during brownout conditions. Images of potential landing hazards were collected under two different contrast conditions. These images were then degraded using a brownout simulation. Human perception experiments were performed to quantify task performance of detecting a hazard under degraded conditions and used to form a model of performance. An observer analysis is performed to quantify the bias and sensitivity of the observers. Data from the highest performing observers is used for further model development. Multiple models are proposed, which include not only the parameters, but also the parameter interactions. Linear regression techniques, logit and probit, are used to fit the models to the data. Models are assessed for goodness using the Akaike Information Criteria. A successful model relates image degradation parameters to task performance and could be used to quantify image processing algorithm performance, as well as provide additional information to automate image processing to achieve task performance.

9071-11, Session 2

Predicted NETD performance of a polarized infrared imaging sensor

Bradley L. Preece, Van A. Hodgkin, Roger W. Thompson Jr., Kevin R. Leonard, Keith A. Krapels, U.S. Army RDECOM CERDEC NVESD (United States)

Polarization filters are commonly used as a simple means of increasing the contrast of a scene thereby increasing sensor range performance. The change in the signal to noise ratio (SNR) is a function of the polarization between the target and background, the orientation of the filter, and the overall transparency of the filter. However, in the midwave and longwave infrared bands, the noise equivalent temperature difference (NETD), which directly affects the SNR, is a function of the filters reemission and its reflected temperature radiance. This paper presents a simple method for tracking the polarization as a function of wavelength, numerical aperture, and signal orientation through Night Vision Integrated Performance Model (NV-IPM) in order to predict the change in SNR and NETD. A host of laboratory and field measurements conducted at Night Vision Electronic Sensors Directorate (NVESD) are utilized to help validate the method and perform design studies of conventional infrared systems equipped with differential polarization filters.

9071-64, Session 2

Modeling segmentation algorithm performance in NV-IPM

Micah J. Lies, Eddie L. Jacobs, The Univ. of Memphis (United States)

Imaging sensors produce images whose primary use is to convey information to human operators. However, their proliferation has resulted in an overload of information. As a result, computational algorithms are being increasingly implemented to simplify an operator's task or to eliminate the human operator altogether. Predicting the effect of algorithms on task performance is currently cumbersome requiring estimates of the effects of an algorithm on the blurring and noise, and "shoe-horning" these effects into existing models. With the increasing use of automated algorithms with imaging sensors, a fully integrated approach is desired. While sensor technologies and algorithms differ, specific tasks can be identified that encompass a wide range. Those tasks are segmentation of objects from the spatio-temporal background, object tracking over time, feature extraction, and transformation of features into human usable information. In this paper research is conducted with the purpose of developing a general performance model for segmentation algorithms based on image quality. A database of pristine imagery has been developed in which there is a wide variety of clearly defined regions with respect to shape, size, and inherent contrast. Both synthetic and "natural" images make up the database. Each image is subjected to various amounts of blur and noise. Metrics for the accuracy of segmentation have been developed and measured for each image and segmentation algorithm. Using the computed metric values and the known values of blur and noise, a model of performance for segmentation is being developed. Preliminary results are reported.

9071-12, Session 3

Technologies for low-bandwidth, high-latency unmanned ground vehicle control

Teresa L. Pace, SenTech, LLC- A DSCI Co. (United States); Lee Hunt, Prioria Robotics, Inc. (United States); Ken Cogan, SenTech, LLC- A DSCI Co. (United States)

Automation technology has evolved at a rapid pace in recent years; however, many real-world problems require contextual understanding, problem solving, and other forms of higher-order thinking that extends beyond the capabilities of robots for the foreseeable future. This limits the complexity of automation which can be supplied to modern unmanned ground vehicles (UGV) and necessitates human-in-the-loop monitoring and control for some portions of missions. In order for the human operator to make decisions and provide tasking during key portions of the mission, existing solutions first derive significant information from a potentially dense reconstruction of the scene utilizing LIDAR, video, and other onboard sensors. A dense reconstruction contains too much data for real-time transmission over a modern wireless data link, so the UGV electronics must first condense the scene representation prior to transmission. The control station receives this condensed scene representations and provides visual information to the human operator; the human operator then provides tele-operation commands in real-time to the UGV. This paper discusses approaches to dense scene reduction of the data required to transmit to a human-in-the loop as well as the challenges associated with them. In addition, the complex and unstructured nature of real-world environments increases the need for tele-operation. Furthermore, many environments reduce the bandwidth and increase the latency of the link. Ultimately, worsening conditions will cause the tele-operation control process to break down, rendering the UGV ineffective. In a worst-case scenario, extreme conditions causing a complete loss-of-communications could result in mission failure and loss of the vehicle. This paper also discusses an autonomy component which enables key activities when the communications link cannot support tele-operation and it also discusses the detection of unsafe or unpredicted conditions occurring during automated operations.

9071-13, Session 3

High-dynamic range imaging using FAST-IR imagery

Frédérick Marcotte, Vincent Farley, Telops (Canada)

One of the biggest and challenging limitations of infrared cameras in surveillance applications is the limited dynamic range. Image blooming and other artefacts may hide important details in the scene when saturation occurs. Many different techniques such as using multiple exposure times have been developed in the past to help overcome these issues. However all these techniques feature non negligible limitations.

This paper presents a new high dynamic range algorithm developed by Telops. It is based on a pixel-wise exposure-time independent calibration as well as a pixel based frame summing. This technique benefits from the use of a high frame rate camera (> 20 000 fps). Description of the hardware is also included. Finally results from a combustion experiment are presented and discussed.

9071-14, Session 3

A virtual environment for modeling and testing sensemaking with multisensor information

Denise M. Nicholson, Sae Schatz, Robert Hoppenfeld, DSCI (United States)

Given the challenges of today's Irregular Warfare (IW), members of small infantry units must be able to function as highly sensitized perceivers throughout large operational areas. Improved Situation Awareness (SA) in rapidly changing, uncertain fields of operation may also save lives of law enforcement personnel and counter-terrorist responders. A critical competency for these personnel is sensemaking: the ability to quickly and accurately assess the environment through the perception of all essential salient environmental and behavioral cues in the environment. This requires the full use of all available intelligence sources including communications, multi-spectral images from unmanned aerial vehicles, night vision goggles, binoculars, optical sights, and laser range finders. Although additional data from improved emerging sensor technologies can increase the understanding of the tactical operating picture, challenges such as interpretation and fusion of the multi-source data and information overload can occur. This paper discusses a Future Naval Capability Research Program, sponsored by the Office of Naval Research, which has developed a virtual environment for analysis and human-in-the-loop testing of perception and decision making performance using state of the art scene simulation and modeled imagery from multi-source systems. We will present results from our human systems engineering approach including 1) the development of requirements and test metrics for individual and integrated system components, 2) the system architecture design 3) images of the prototype virtual environment testing system and 4) a discussion of the current and future testing capabilities of the system. In particular, we will examine the potential to model, test and analyze the impact of advances in sensor spatial, spectral, and temporal resolution to a user's sensemaking capability and small unit operational readiness.

9071-15, Session 3

Performance assessment of compressive sensing imaging

Todd W. Du Bosq, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Compressive sensing (CS) can potentially form an image of equal quality to a large format, megapixel array, using a smaller number of individual measurements. This has the potential to provide smaller, cheaper, and lower bandwidth imaging systems. To properly assess the value of such systems, it is necessary to fully characterize the image quality, including artifacts, sensitivity to noise, and approach limitations. Full resolution imagery of an eight tracked vehicle target set at range was used to simulate CS measurements and reconstruct images from a single-pixel CS camera for various levels of compression and noise. For comparison, a traditional camera was also simulated setting the number of pixels equal to the number of CS measurements in each case. Human perception experiments were performed to determine the identification performance within the trade space. The performance of the nonlinear CS camera was modeled with the Night Vision Integrated Performance Model (NV-IPM) by mapping the nonlinear degradations to an equivalent linear shift invariant model. Finally, the limitations of compressive sensing modeling will be discussed.

9071-16, Session 3

Low-cost computational imaging infrared imaging

Kyle R. Bryant, U.S. Army Research, Development and Engineering Command (United States); Ryan K. Rogers, William Derrick Edwards, Dynetics, Inc. (United States)

Computational imaging techniques can be used to extend the depth of field of imaging sensors such that the sensors become less expensive to build and athermalize with no loss to performance. Optical phase can be manipulated to create an image that is optimized for a detection and tracking algorithm as well as reconstructed digitally to form an image suitable for viewing. A typical low-cost sensor which is used for target detection and tracking may run an algorithm which requires different features and resolution from its imagery than would a system optimized for a human. This offers a unique opportunity to optimize both optics and image processing for a system which can maximize mission performance as well as minimize production cost. Simple computational techniques have not yet been successful in passive, low-signal environments due to noise issues. This study examines the use of a simple computational technique in an algorithmic application in which optimal reconstruction may occur with lower noise. This paper will describe the model, simulation, and prototype which resulted from a detailed and novel system design and modeling process. The goal of this effort is to accurately model the anticipated performance and to prove actual cost savings of a tracking sensor which employs computational imaging techniques.

9071-18, Session 4

Night vision integrated performance model for camera calibration and prediction

David P. Haefner, Jonathan D. Fanning, Brian P. Teaney, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The Night Vision Integrated Performance Model (NV-IPM) is a system engineering tool developed to provide an intuitive platform for component and parameter based trade studies. The success of this tool is rooted in its ability to accurately trace photons from an arbitrary scene through a specified atmosphere and each component in an imaging device (optics, filters, sensors, etc.) up to and including the human visual system. NV-IPM can also be used in conjunction with laboratory measurements to provide an accurate assessment of system performance with respect to theoretical specifications. The measured component can then be used to conduct trade studies across scenes and situations beyond those measured. In this article, we demonstrate how NV-IPM can be used to accurately predict various aspects of color imaging system performance (blur, signal, and noise) using a linear shift invariant representation of the system. The modeled performance shows excellent agreement with measurements for both monochromatic and colored scenes.

9071-19, Session 4

Imaging system sensitivity analysis with NV-IPM

Jonathan D. Fanning, Brian P. Teaney, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

This paper describes the sensitivity analysis capabilities to be added to a future version of the NVESD imaging sensor model NV-IPM. Imaging system design always involves tradeoffs to design the best system possible within size, weight, and cost constraints. In general, the performance of a well designed system will be limited by the largest, heaviest, or most expensive component. Modeling is used to analyze system designs before the system is built. Traditionally, NVESD models were only used to determine the performance of a given system design. NV-IPM has the added ability to automatically determine the sensitivity of any system output to changes in the system parameters. The component-based structure of NV-IPM tracks the dependence between outputs and inputs such that only the relevant parameters are varied in the sensitivity analysis. This allows sensitivity analysis of an output such as probability of identification to determine the limiting parameters of the system. Individual components can be optimized by doing sensitivity analysis of outputs such as NETD or SNR. This capability will be demonstrated by analyzing example imaging systems.

9071-20, Session 4

Modeling laser radar systems in the Night Vision Integrated Performance Model (NV-IPM)

Kevin R. Leonard, Van A. Hodgkin, Bradley L. Preece, Roger W. Thompson Jr., Keith A. Krapels, U.S. Army RDECOM CERDEC NVESD (United States)

Active imaging systems are currently being developed to increase the target acquisition and identification range performance of electro-optical systems. This paper reports on current efforts to extend the Night Vision Integrated Performance Model (NV-IPM) to include laser radar (LADAR) systems for unresolved targets. Experimental data for an exemplar target are compared with modeled results.

Combining this new LADAR modeling capability with existing sensor and environment capabilities already present in NV-IPM will enable modeling and trade studies for military relevant systems.

9071-21, Session 4

NV-IPM components for full-spectrum irradiance and path radiance using Modtran

Joseph P. Reynolds, Brian P. Teaney, U.S. Army RDECOM CERDEC NVESD (United States)

The Night Vision Integrated Performance Model (NV-IPM), recently released by the US Army Night Vision and Electronic Sensors Directorate (NVESD), now uses full spectral modeling throughout the image chain. The spectral signal is only collapsed at points in the chain where it is physically combined, such as broad band detectors and the human visual system. The initial release of the model uses the standard spectral irradiance data from previous Night Vision models. This legacy data only spans wavelengths from 400 nm to 2000 nm, and the atmospheric conditions and solar/lunar geometries are limited. A new component developed for NV-IPM utilizes Modtran to calculate ground irradiance over a broader range of conditions, including all night conditions, covering wavelengths from 300 nm to 15000 nm. In addition, a new Modtran atmospheric transmission component will calculate target and background path radiance, for cases where the sky-to-ground ratio approximation is unknown or inaccurate. Both components will be available in a future version of NV-IPM.

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9071-22, Session 5

Modeling static and dynamic detection of humans in rural terrain

Eric A. Flug, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Historically, the focus of detection experiments and modeling at the Night Vision and Electronic Sensors Directorate (NVESD) has been on detecting military vehicles in rural terrains. A gap remains in understanding the detection of human targets in rural terrains and how it might differ from detection of vehicles. There are also improvements that can be made in how to quantify the effect of human movement on detectability. Two experiments were developed to look at probability of detection and time to detect of fully exposed human targets in a low to moderate clutter environment in the Infrared. The first test uses static images of standing humans while the second test uses videos of humans walking across the scene at various ranges and speeds. In addition to developing Acquire parameters for use in wargaming, task difficulty parameters (V50's) are calculated to calibrate NVESD sensor performance models, specifically NVThermIP and NV-IPM, for these tasks. Results will be presented along with a discussion about the computation of contrast for small targets, the effect of motion on detection, and a description of follow-on work.

9071-23, Session 5

Uncertainty analysis of sensor abilities in the short-wave infrared spectral region based on nightglow as the main lightsource

Thomas Svensson, Swedish Defence Research Agency (Sweden)

Images collected in the short-wave infrared (SWIR) spectral range are similar to visual (VIS) images and are easier to interpret for a human operator than images collected in the thermal infrared. Another big advantage is the ability to penetrate ordinary glass which also means that conventional lens materials can be used. A drawback is that the sensor's abilities to work under dark conditions are dependent on external light sources. At moonless conditions, the dominant natural light source is nightglow, whose level is significantly higher in SWIR compared to VIS. However, local and temporal variations of nightglow, like variations in other measurands, give rise to measurement uncertainties. Therefore, real abilities for SWIR cameras under dark conditions can be quite different compared with predicted abilities. In this paper the variation of the nightglow intensity is quantified by estimation of standard uncertainties. The standard uncertainties are compared with calculated combined standard uncertainties.

9071-24, Session 5

A uniform method for modeling target acquisition with indepentent networkd imaging sensors

Melvin H. Friedman, U.S. Army RDECOM CERDEC NVESD (United States)

The search problem discussed in this paper is easily stated: given time-dependent search parameters (P_∞,?) for a single sensor searching for a single target, calculate how the probability a single observer acquires a target grows with time. In a previous paper, by requiring the solution satisfy six requirements, the solution was expressed in terms of recursion relationships which used specialized functions. The code using recursion relationships is intricate. The analytical solution in this paper requires one assumption, and is easier to code and understand than the previous solution. The results of this paper may find application in war game modeling.

9071-25, Session 5

General design considerations for high-performance mobile land-based EO/IR pointing and tracking systems

Michael N. Sweeney, General Dynamics-Global Imaging Technologies (United States)

High performance and mobile pointing and tracking systems are critical for future battlefield management. These systems can detect, identify, and track a broad spectrum of potential threats including missiles, projectiles, and aircraft. Multi-spectral performance from visible through long wave infrared using multiple zoom optical systems and sensors that are commonly boresighted provide maximum utility to detect, identify, geo-locate, and track targets under all day/night, weather and battlefield conditions over long ranges. Scene stabilization, high frame rates, time-stamped synchronization of images among coordinated assets, and covert communication networking is critical to automated operational supremacy within the environment by prioritizing and activating rapid and appropriate responses. Modularity and open architecture for all of the major mechanical, electrical, optical, firmware and software elements is also critical for ease of performance upgrade, mission re-configuration, reliability, maintenance, and life cycle cost.

Novel optical systems including reflective, refractive, and catadioptric designs, both fixed focal length and continuous zoom, servicing visible, SWIR, MWIR, and LWIR wavelength spectrums, are being continuously improved within industry. Advances in optical design and manufacturing enable unprecedented optical performance for a given aperture and package size. A wide variety of cooled and uncooled high fidelity focal plane arrays are available or emerging to match advances in optical systems, scene stabilization, and video processing. Very high video frame rates are required to adequately image fast moving targets. Structurally optimized gimbal structures, precision ball bearings, rotary pivot flexures, motors, and angular position sensors combined with advances in electronic stabilization ensure crisp and low jitter images simultaneously among all of the sensors that comprise the EO/IR payload.

The following discussion examines the confluence of optical, sensor, and pointing technologies required for seamless immersion within sophisticated battlefield communication and management systems. Notional and real-life examples are profiled in the context of trade-off discussions.

9071-26, Session 5

SWIR range performance prediction for long-range applications

Emanuele Guadagnoli, Piero Ventura, Gianni Barani, Antonio Porta, SELEX Galileo S.p.A. (Italy)

Long range imaging systems have applications in vessel traffic monitoring, border and coastal observation, and generic surveillance. Often, sign reading and identification capabilities are required, and medium- or long-wave infrared systems are simply not the best solution for these tasks, because of the low scene contrast. Among reflected light imagers, the short-wave infrared has a competitive advantage over the visible and near-infrared spectrum, being less affected by path attenuation, scattering and turbulence. However, predicting a SWIR system long range performance still represents a challenge because of the need of an accurate atmospheric modelling.

In this paper, we present the key limiting performance factors for long range applications, and how we used popular atmospheric models to extract the synthetic simulation parameters needed for range performance prediction. We then present a case study for a long range application, where the main requirement is to read a vessel name at distances greater than 10km. The results show a significant advantage of SWIR over visible and near-infrared solutions for long range identification tasks.

9071-27, Session 6

Methodology for lens transmission measurement in the 8-13 micron waveband: Integrating sphere versus camera-based

Norbert Schuster, Jan Verplancke, Bergeron S. Salethaiyan, John W. Franks, Umicore Electro-Optic Materials (Belgium)

Transmission is a key parameter in describing a lens, but is also often the subject of controversy. Most published lens transmission values are based on spectrophotometric measurement of plane-parallel witness pieces obtained from coating processes.

The difficulty in accurately estimating lens transmission lies in measuring the ratio between the signal of ray bundles deviated by the lens under test and the signal of non-deviated ray bundles without lens (100% transmission). Sources for mistakes in LWIR are manifold: background radiation, reflection from “rough” surfaces, and/or unexpected transmission bands.

Two different setups are built and tested: An integrating sphere-based setup and a camera-based setup. After some mechanical modifications on initial setups, measured signals without lens and with lens under test stabilize. Reference elements such as an uncoated ZnSe-lens are used for calibration of both setups. Respecting solid angle-based radiometric relations, both setups yield consistent transmission values.

Setups and their calibration will be described and test results on commercially available lenses will be published.

9071-28, Session 6

Modulation transfer function measurement of microbolometer focal plane array by Lloyd’s mirror method

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Today, both military and civilian applications require miniaturized and cheap optical systems. One way to achieve this trend consists in decreasing the pixel pitch of focal plane arrays.

In order to evaluate the performance of the overall optical systems, it is necessary to measure the modulation transfer function (MTF) of these pixels. However, small pixels lead to higher cut-off frequencies and therefore, original MTF measurements that are able to extract frequencies up to these high cut-off frequencies, are needed.

In this paper, we will present a way to extract 1D MTF at high frequencies by projecting fringes on the FPA. The device uses a Lloyd mirror placed near and perpendicular to the focal plane array. Consequently, an interference pattern of fringes can be projected on the detector. By varying the angle of incidence of the light beam, we can tune the period of the interference fringes and, thus, explore a wide range of spatial frequencies, and mainly around the cut-off frequency of the pixel which is one of the most interesting area.

Illustration of this method will be applied to a 640x480 microbolometer focal plane array with a pixel pitch of 17μm in the LWIR spectral region.

9071-29, Session 6

So that’s what space invariant means: how to measure and report NETD

William Derrick Edwards, Ryan K. Rogers, Dynetics, Inc. (United States); Kyle R. Bryant, Christopher L. Dobbins, Samuel B. Wood, U.S. Army Research, Development and Engineering Command (United States)

For over 30 years, the U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) has specialized in characterizing the performance of infrared (IR) imaging systems in the laboratory and field. In the late 90’s, AMRDEC developed the Automated IR Sensor Test Facility (AISTF) which allowed efficient deployment testing of Unmanned Aerial System (UAS) payloads. More recently, AMRDEC has tested many uncooled infrared (UCIR) sensor systems that have potential size, weight, power, and cost (SWAPC) benefits for certain fielded U.S. Army imaging systems. To compensate for relatively lower detector sensitivities, most UCIR systems operate with very fast f/# optics. When measuring the Noise Equivalent Temperature Difference (NETD) the techniques used to measure traditional cooled infrared systems are invalid when applied to systems with f/#’s faster than 2.5. Currently the industry standard procedure for measuring NETD artificially boosts response thereby improving NETD; this is incorrect and does not represent the actual sensitivity of a system in the field. Additionally, in order to compare these camera cores or sensor systems to one another, it is imperative to scale the NETD values for f/# and waveband differences accurately. This paper will outline proper measurement techniques to report camera core and system level NETD, as well as demonstrate methods to scale the metric for changes in waveband and f/#.

9071-30, Session 6

Test equipment and method to characterize a SWIR digital imaging system

John Green, Tim Robinson, Esterline Control Systems (United States)

Shortwave Infrared Focal Plane Array (SWIR FPA) Imaging Systems are an invaluable tool for many aviation applications. This is largely based on technology improvements for sensitivity, resolution, frame rate, size reduction, the ability to use the system without active cooling, and unit cost. The Air Force Research Laboratory (AFRL) has particular interest in the possibility that a helmet mounted FPA imaging systems may offer a significant advantage to the US war fighter by providing enhanced night and day vision.

There are several manufacturers of uncooled SWIR infrared cameras. Given the number of manufactures and various camera options available, it is beneficial to characterize the imaging systems using common test methods. By adopting a common analysis method, the performance of various imaging systems manufactured by different OEMs can be compared. This can be achieved by testing these systems on a common “Test Bench” using standard test procedures.

This paper proposes a testing system designed to characterize a digital imaging system. The proposed testing system was developed under the AFRL research contract Advanced Night Vision Imaging System – Cockpit Integration. The equipment and test procedures developed under this contract provide the means to independently characterize the performance of SWIR imaging systems. The test equipment is capable of measuring relative spectral responsivity, noise equivalent irradiance, dynamic range, linearity, dark noise, image uniformity, and image artifacts.

9071-31, Session 6

Calibration of uncooled LWIR microbolometer imagers to enable long-term field deployment

Paul W. Nugent, Joseph A. Shaw, Montana State Univ. (United States)

We describe radiometric calibration methods that enable long-term deployment of uncooled microbolometer infrared imagers without on-board calibration sources. These methods involve tracking the focal-plane-array and camera-body temperatures and compensating for the changing camera response. The compensation is derived from laboratory measurements with the camera viewing a blackbody source while the camera temperature is varied in a thermal chamber. Results are shown that demonstrate absolute temperature uncertainty of 0.35 degrees C or better over a 24-hour period, with more than half of this uncertainty inherent in the blackbody source to which the measurements are compared. This work was driven by environmental remote sensing applications, but the calibration methods are also relevant to a wide range of infrared imaging applications.

9071-32, Session 7

IR microbolometer array spectral response measurement and angular effect using FTIR

Aurelie Touvignon, Fabien Romanens, Julien Favreau, Alain Durand, ULIS (France); Olivier Gravrand, CEA-LETI (France); Christel-Loïc Tisse, ULIS (France)

To appreciate the impact of technological recipes’ evolution on the spectral response of micro-bolometer array and to estimate their membrane mechanical stability, ULIS is using an original method which consists of measuring the spectral response of detector array over a large part of the detector simultaneously. This is done by tweaking the standard protocol of commercial FTIR where the IR detector of the FTIR is replaced by the array to be measured. All the calculation are taken care externally (interferogram processing). We use this new set up to perform tests on the angular spectral response of an IR detector and to analyse the relationship between spectral response and pixel mechanical behaviour.

In this paper, ULIS presents the setup of this measurement as well as the technical issues that needed to be addressed. We will also show measurement results performed on 17µm pitch pixels with normal incidence and with different tilt angles. We will then try to shed some theoretical light on the results and the limitations of this protocol using simple optical cavity modelling.

9071-33, Session 7

NVLabCAP: an NVESD-developed software tool to determine EO system performance

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

Engineers at the US Army Night Vision and Electronic Sensors Directorate have recently developed a software package called NVLabCap. This software not only captures sequential frames from thermal and visible sensors, but it also can perform measurements of signal intensity transfer function, 3-dimensional noise, field of view, super-resolved modulation transfer function, and image bore sight. Additionally, this software package, along with a set of commonly known inputs for a given thermal imaging sensor, can be used to automatically create an NV-IPM element for that measured system. This model data can be used to determine if a sensor under test is within certain tolerances, and this model can be used to objectively quantify measured versus given system performance.

9071-34, Session 7

NIST traceable measurements of radiance and luminance levels of night-vision-goggle test-instruments

George P. Eppeldauer, Vyacheslav B. Podobedov, National Institute of Standards and Technology (United States)

In order to perform radiance and luminance level measurements of night-vision-goggle (NVG) test instruments, NIST developed new-generation transfer-standard radiometers (TR). The new TRs can perform low-level radiance and luminance measurements with SI traceability and low uncertainty. The TRs were calibrated against NIST detector/radiometer standards holding the NIST photometric and radiometric scales. An 815 nm diode laser was used at NIST for the radiance responsivity calibrations. A spectrally flat filter correction was made for the TRs to correct the spectral responsivity change of the built-in Si photodiode for LEDs peaking at different wavelengths in the different test sets. The radiance responsivity transfer with its uncertainties are discussed.

At present, the manufacturer of the NVG test instruments (test sets) converts the output radiance into equivalent luminance that can be manually set on the test set. The calibration factor, which is the radiance to equivalent-luminance ratio, (introduced by the manufacturer) is analyzed in this work. The radiance values that belong to the selected different equivalent luminance values were measured with the TRs. The TRs propagate the traceablity to the NIST detector-based reference scales. There are two basic luminance levels in a test set. A fixed 1fL is provided by a green LED for instrument checkup. In addition, equivalent-luminance levels, produced by an IR-LED source that peaks at about 815 nm, can be selected (adjusted) from zero to 3 mfL. A user selected low output-radiance level of the test-set can be used for NVG gain determinations. Both the fixed 1 fL luminance of the test-set (set by the manufacturer) and the integrated output-radiance (for equivalent luminance levels equal to or higher than 10^-4 fL) were measured with the TRs. The highest standard deviation of the mean was 0.6 %. The radiance uncertainty obtained from the three TR measurements was 4.6 % (k=2) at 10^-4 fL. The obtained deviations of

the measured calibration factors from the 2.48 x 10^-6 W fL / (cm^2 sr) calibration factor (for 1 fL equivalent luminance) were about 9 %. The output radiance of a commercial IR sphere source (earlier used as standard) and the radiance responsivity of a secondary standard commercial detector unit, which was originally calibrated against the commercial IR sphere source, were also measured with the TRs. The performances of the NVG test instruments were evaluated and the manufacturer produced radiance and luminance levels were calibrated with SI/NIST traceability.

9071-35, Session 7

An alternate method for performing MRTD measurements

Alan Irwin, Jack T. Grigor, Santa Barbara Infrared, Inc. (United States)

The Minimum Resolvable Temperature Difference test (MRTD) is one of the tests typically required to characterize the performance of thermal imaging systems. The traditional test methodology is very time intensive, requiring data collection at multiple temperatures and target frequencies. This paper will present an alternate methodology using a controlled blackbody temperature ramp rate. This allows selection of the temperature at which a target is determined “resolved” without stopping.

MRTD curves generated from data collected at multiple ramp rates and target frequencies is compared with MRTD curves using the same target frequencies and settled temperatures. The same sensor and test hardware is used for each data collection. Testing is conducted by multiple trained observers. Multiple ramp rates will be Test results using the traditional method will be compared to test results using this alternate method.

9071-36, Session 7

Testing military sensor systems in the laboratory and field

James McKechnie, Jack T. Grigor, Alan Irwin, Santa Barbara Infrared, Inc. (United States)

Testing of military sensor systems presents unique problems to test personnel whether in the laboratory or the field. Military sensors include active and passive systems operating in the visible, NIR, SWIR, MWIR, and LWIR, typically imaging systems, laser range finders/designators and illuminators. Performance is typically defined in terms of resolution, sensitivity, range, power, etc.

Sensor requirements are defined by the end user in terms of target detection, recognition, and discrimination. Sensor manufacturers define performance in more technical terms such as MTF, MRTD, resolution, beam divergence and other figures of merit. Correlating test results with the end users requirements is problematic. This paper discusses this gap.

9071-37, Session 8

Characterization of SWIR cameras by MRC measurements

Martin Gerken, Harry H. Schlemmer, Hubertus A. Haan, Christofer Siemens, Mario O. Münzberg, Cassidian Optronics GmbH (Germany)

Cameras for the SWIR wavelength range are becoming more and more important because of the superior observation range for day-light operation under adverse weather conditions (haze, fog, rain). In order to qualify a camera for a given application characterization of the camera by means of the Minimum Resolvable Contrast MRC concept is favorable as the MRC comprises all relevant properties of the instrument. With the MRC known for a given camera device the achievable observation range can be calculated for every combination of target size, illumination level or weather conditions one can think of.

The MRC measurement can be performed widely along the guidelines of the MRC measurement of a visual camera. Typically measurements are performed with a set of resolution target (e.g. USAF Target 1951) manufactured with different contrast values from 50% down to less than 1%. For a given illumination level the achievable spatial resolution is measured for every target.

To use this method for SWIR cameras the irradiation parameters have to be translated from the photometric units to radiometric units. A radiation source is necessary with appropriate emission in the SWIR range (incandescent lamp) the irradiance of which is measured in W/m? instead of Lux = Lumen/m?. Furthermore, the contrast values of the targets may differ from the values determined for the visual range and thus have to be calibrated newly for the SWIR range. In addition, the SWIR illumination levels for typical daylight and twilight conditions have to be defined.

The measured MRC values of some cameras are compared to the specified performance data of the devices.

9071-38, Session 8

Wafer level test solutions for IR sensors

Sebastian Giessmann, Frank-Michael Werner, Cascade Microtech GmbH (Germany)

Wafer probers provide an established platform for performing electrical measurements at wafer level for CMOS and similar process technologies. For testing IR sensors, the requirements are beyond the standard prober capabilities. This presentation will give an overview about state of the art IR sensor probing systems reaching from flexible engineering solutions to automated production needs.

Cooled sensors typically need to be tested at a target temperature below 80 K. Not only is the device temperature important but also the surrounding environment is required to prevent background radiation from reaching the device under test. To achieve that, a cryogenic shield is protecting the movable chuck. By operating that shield to attract residual gases inside the chamber, a completely contamination-free test environment can be guaranteed. The use of special black coatings are furthermore supporting the removal of stray light. Typically, probe card needles are operating at ambient (room) temperature when connecting to the wafer. To avoid the entrance of heat, which can result in distorted measurements, the probe card is fully embedded into the cryogenic shield. A shutter system, located above the probe field, is designed to switch between the microscope view to align the sensor under the needles and the test relevant setup. This includes a completely closed position to take dark current measurements. Another position holds a possible filter glass with the required aperture opening. The necessary infrared sources to stimulate the device are located above.

Uncooled sensors (microbolometer) also have challenging test requirements. The integration of those requirements is presented as well.

9071-39, Session 9

An affordable 7.7 to 12.3 micron spectral imager using a cooled detector array and high-resolution circular variable filter (CVF): system description and performance

Dario Cabib, CI Systems (Israel) Ltd. (Israel)

Spectral imagers in the Long Wave IR spectral range (8 to 12 microns) suffer from the problem of high production costs because the existing commercial cooled array detectors are expensive, and in fact they are prohibitively expensive for many applications.

As a result, the drive to lower the cost of Long Wave IR spectral imagers is strong: this was the main motivation for CI to propose a new design that allows these spectral imagers to be more affordable. One area of possible cost reduction without relinquishing the advantages of a cryogenically cooled detector is the method used to provide the spectral information. CI Systems has developed a long wave IR (7.7 to 12.3 micron) spectral imager concept using a Circular Variable Filter (CVF), (a proprietary component based on multiple layer interference filter technology) which has advantages over the interferometric Fourier Transform method commonly used in this spectral range. The CVF method has its own development challenges; however, once proven, this concept may be more suitable and affordable for applications in which a spectral resolution of 0.5% of the wavelength (or 50 nm at 10 microns) is required. The design of the optical system must minimize background signals without being cooled to cryogenic temperatures, so we called it VIrtually COld (or VICO). After publishing the first prototype characterization data in September 2013 we present in this paper additional and more advanced measurement examples and performance data.

9071-40, Session 9

High-dynamic range and high-speed imaging in the TELOPS FAST-IR 1500 midwave infrared camera

Frédérick Marcotte, Vincent Farley, Telops (Canada); Myron R. Pauli, U.S. Naval Research Lab. (United States)

A new generation Midwave Infrared Camera, FAST-IR 1500, by TELOPS allows full imaging at 1500 This allows access to image high speed phenomena with high temporal as well as spatial resolution. Examples of such high speed phenomena are ballistic impacts and muzzle flashes. The faster frame rate also provides more robustness against some types of temporal clutter such as solar glint which can interfere with detection and identification of objects of interest.. Additionally, a combination of short and long integration times can allow a higher dynamic range imaging than in a single integration time camera. The TELOPS™ FAST-IR 1500 camera has integration times that can range from 6 ?s to > 500 ?s. The camera is also capable of imaging a window of 128 x 32 or 64 x 64 at 20000 Hz. The camera also contains fast-switching neutral density filters which can increase sensor dynamic range by several orders of magnitude if needed. In other words, bright and dim objects can be discerned instead of just choosing between imaging only bright objects or imaging only dim objects with bright objects in saturation. Selected scenes at various signal-to-noise and signal-to-background ratios will be shown at different frame rates with analysis of the appropriate detection metrics relating to target detection, target tracking, and scene dynamic range. Measurements and analysis indicates that short integration time images can be summed/integrated digitally to obtain high sensitivity imagery with very small losses compared to low speed (large integration time) imagery.

9071-41, Session 10

Evaluation of turbulence mitigation methods

Adam W. M. van Eekeren, TNO Defence, Security and Safety (Netherlands); Claudia S. Huebner, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany); Judith Dijk, Klamer Schutte, Piet B. W. Schwering, TNO Defence, Security and Safety (Netherlands)

Atmospheric turbulence is a well-known phenomenon that diminishes the recognition range in visual and infrared imagery. There exist many different methods to compensate for the effects of turbulence. Some use a hardware approach, such as adaptive optics, some use a software approach. This paper focuses on the performance of two software-based methods to mitigate the effects of low- and medium turbulence conditions. Both methods are capable of processing static and dynamic scenes. The first method consists of local registration, frame selection, blur estimation and deconvolution. The second method consists of local motion compensation, fore-/background segmentation and weighted iterative blind deconvolution. A comparative evaluation is done on some representative sequences captured during a NATO SET 165 trial in Dayton. The benefits and costs of different processing steps, such as local registration and frame selection, will be evaluated using quantitative measures. The amount of blurring and tilt in the imagery are relevant measures for such an evaluation. It is shown that both methods improve the imagery by reducing the blurring and tilt and therefore enlarge the recognition range. Furthermore the measurements will be compared with the characteristics of the optical system, which will give an insight of the maximum obtainable performance.

9071-42, Session 10

Fourier transform infrared (FTIR) spectroscopy and micro-pulse lidar (MPL) atmospheric inversion technique to characterize path radiance

Michael E. Thomas, Andrea M. Brown, David M. Brown, Cadence A. Martin, Shadrian B. Strong, Marc B. Airola, Johns Hopkins Univ. Applied Physics Lab. (United States)

The combination of a near-infrared (NIR) aerosol lidar and a midwave-infrared (MWIR) spectroradiometer are used to determine the vertical aerosol absorption and extinction profile in a coastal environment. When available for clear sky daytime measurements a multichannel sun photometer is also used. The sun photometer provides path integrated optical depths. Because of the broad spectral coverage a more complete characterization of the aerosol is achieved. A bimodal hydrosol model is used to connect the various measurements requiring particles in the micron and 10s of nm size range. The micron sized particles are most important in the NIR/visible region. The nm sized particles and most important in the MWIR and LWIR spectral regions. To extract aerosol information from a down welling spectral radiance measurement, the 4-micron window region is utilized. This requires correction from molecular continuum contributions, in particular the far blue wing of the asymmetric stretch band of CO2.

9071-43, Session 10

Developing a broad spectrum atmospheric aerosol characterization for remote sensing platforms over desert regions

Shadrian B. Strong, Andrea M. Brown, Johns Hopkins Univ. Applied Physics Lab. (United States)

Remotely sensed imagery of targets embedded in Earth's atmosphere requires characterization of aerosols between the space-borne sensor and ground to accurately analyze observed target signatures. The impact of aerosol microphysical properties on retrieved atmospheric radiances has been shown to negatively affect the accuracy of remotely sensed data collects. Temporally and regionally specific meteorological conditions require exact site atmospheric characterization, involving extensive and timely observations. Alternatively, climatologically-based assessments may minimize significant short-term changes. We present a methodology to utilize a subset of ground-based data collected near two sites in White Sands New Mexico that provides aerosol properties including asymmetry, optical depth, absorption/extinction coefficients, and indices of refraction from the visible to long-wave infrared wavelengths for seasonal radiative analysis. Daily averaged data is input in the radiative transfer model MODTRAN 5 in order to assess differences between aerosol properties retrieved from ground versus space from the NASA Aqua MODIS instrument. We find atmospheric radiance correction factors to be the greatest in the short-wave (1.3 – 3 μm) and long-wave (7 – 9 μm) infrared regions, are highly site-specific, and do not appear to have a seasonal correlation, while the transmittance correction factors exhibit consistent seasonal trends among sites.

9071-44, Session 10

Spectrally dependent hydrated aerosol signatures observed in maritime environments

Shadrian B. Strong, Michael E. Thomas, Andrea M. Brown, Mary R. Keller, Johns Hopkins Univ. Applied Physics Lab. (United States)

Recent FTIR atmospheric observations in maritime environments, such as Hawaii, have often revealed clear, high-visibility conditions at visible and shortwave infrared wavelengths, but exhibit significant attenuation in the mid-wave- and long-wave-infrared. This phenomenon is not unique, as it has been observed by airborne spectral imaging systems. However, its cause has not been definitively proven nor correlated with precise meteorological conditions. One theory for these observations is the existence of small hygroscopic particulates (< 200 nm in diameter) that are too small to scatter visible light but which may have significant absorption effects in the thermal infrared. The effect of these particulates is anticipated to be greatest in high-humidity environments, such as those found in tropical locations. This effect is difficult, if not impossible, to replicate with available radiative transfer models, given the need to produce high transmission at visible wavelengths and reduced transmission in the thermal infrared with limited aerosol characterization capabilities. Consequentially, model-based atmospheric characterization for sensors from the visible to long-wave infrared would require different atmospheric parameterizations for path radiance and transmittance corrections in such environments. In a step towards developing broad-spectrum atmospheric characterization, we compare our maritime FTIR measurements with a preliminary model of hydrated aerosol particulates and evaluate these data against Weather Research Forecast (WRF) numerical weather model simulations of aerosol concentrations.

9071-45, Session 10

Fourier transform infrared spectroscopy (FTIR) characterization of atmospheric fluctuations along slant paths

Cadence A. Martin, Michele B. Lohr, Michael E. Thomas, David M. Brown, Shadrian B. Strong, Johns Hopkins Univ. Applied Physics Lab. (United States)

Sensor system noise needs to be known to determine the limits of detecting a feature. For passive infrared spectral sensors the noise is characterized in terms of the noise equivalent spectral radiance, NESR. The net NESR (NESR_net) has two components, the internal NESR of the instrument (NESR_instr) and the external NESR of the path being viewed by the sensor (NESR_path). For an FTIR, the NESR_instr is measured by viewing a stable blackbody and computing the standard deviation of the sine transform of the interferogram. NESR_net is then measured by viewing a scene and computing the standard deviation of the sine transform of the interferogram. NESR_path is then determined knowing the instrument and net NESR. NESR_path is driven by temperature and species concentration fluctuations along a path and can dominate over the instrument noise.

9071-46, Session 11

Validation of atmospheric turbulence simulations of extended scenes

Kevin R. Leonard, Richard L. Espinola, U.S. Army RDECOM CERDEC NVESD (United States)

Atmospheric turbulence causes blur, distortion and intensity fluctuations that can severely degrade image quality of electro-optic and thermal imaging systems. Realistic simulated imagery is needed to evaluate the effects of turbulence and provide input for evaluation of mitigation and image processing algorithms since turbulence-based data collections can be cost prohibitive and time consuming. In this work we validate an existing turbulence image simulator against a well characterized dataset, including two-handed weapons and resolution targets. The robust dataset was collected through a diurnal cycle for a variety of ranges and sensor systems.

9071-47, Session 11

Aerosol MTF revisited

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Different views of the significance of aerosol MTF have been reported. For example, one recent paper [OE, 4/2013, pp. 046201] claims that the aerosol MTF “contrast reduction is approximately independent of spatial frequency, and image blur is practically negligible”. On the other hand, another recent paper [JOSA A, 11/2013, pp. 2244-2252] claims that aerosols “can have a non-negligible effect on the atmospheric point spread function”. We present clear experimental evidence of common significant aerosol blur and evidence that aerosol contrast reduction can be extremely significant. In the IR, it is more appropriate to refer to such phenomena as aerosol-absorption MTF. The reason is that the aerosol MTF includes transmission and absorption effects,by all particulates including air molecules, and in the IR the atmospheric absorption is usually much more significant than scatter. Consequently, relative humidity has a critical role in determining thermal image resolution according to atmospheric transmission.The role of imaging system instrumentation on such MTF is addressed too. Field of view, for example, in the visible and NIR limits received scattered light to very small angles of forward scatter as described by the aerosol phase scattering function which is anyway strongly biased towards very small scattering angles. In the thermal IR, this truncation may be even stronger because there is less scatter. These effects truncate the aerosol-absorption PSF, thus decreasing blur size but at the same time increasing aerosol-absorption MTF spatial frequency bandwidth by orders of magnitude. Conservation of energy causes atmospheric absorption to decrease aerosol-absorption MTF in a spatial frequency dependent manner, thus contradicting the OE paper.

9071-48, Session 11

DARPA superresolution vision system (SRVS) robust turbulence data collection and analysis

Richard L. Espinola, Kevin R. Leonard, Roger W. Thompson Jr., U.S. Army Night Vision & Electronic Sensors Directorate (United States); David H. Tofsted, Michael S. D’Arcy, U.S. Army Research Lab. (United States)

Atmospheric turbulence degrades the range performance of military imaging systems, specifically those intended for long range ground to ground target identification. The recent Defense Advanced Research Projects Agency (DARPA) Super Resolution Vision System (SRVS) program developed novel post-processing system components to mitigate turbulence effects on visible and infrared sensor systems. As part of the program, the US Army RDECOM CERDEC NVESD and the US Army Research Laboratory Computational & Information Sciences Directorate (CISD) collaborated on a field collection and atmospheric characterization of a two-handed weapon identification dataset through a diurnal cycle for a variety of ranges and sensor systems. The robust dataset is useful in developing new models and simulations of turbulence as well as a standard baseline for comparison of sensor systems in the presence of turbulence degradation and mitigation. In this paper, we describe the field collection and atmospheric characterization and present the robust dataset to the defense, sensing, and security community. In addition, we present an expanded model validation of turbulence degradation using the field collected video sequences.

9071-49, Session 11

Multiple angle analysis of optical backscatter measurements for determination of cloud particulates for UAV/weather balloon applications

Rahul Dixit, David J. Klotzkin, Binghamton Univ. (United States)

It is crucial for an aircraft to know the environment in which it is flying to avoid ash particulates and potential for icing. Optical backscattering provides enormous information but it can be difficult to interpret. In this paper, we present an algorithm for determination of size information of water droplets, distinguishing of water from ice, and identification of concentration of ash particles. The information is acquired from a simple, integrated, unmanned-aerial-aircraft (UAV) worthy system that takes optical backscattering measurements at a variety of angles and scattering wavelengths and two polarizations. In this work, two collimated, concentric and polarized lasers illuminate the sample volume. From the reflected polarization ratio at 135°, the mean water droplet size and their number density can be determined over a range of 1-50μm microns with a resolution of 5μm. Sample density can be determined by signal amplitude. Detection of silica particles is incorporated by examining the response ratio at 90° to 135°. Measured results and agreement with theoretical calculations will be reported.

9071-50, Session 11

Three-dimensional temperature estimation of a fire plume using multiple longwave infrared camera views

Michele B. Lohr, Michael E. Thomas, Todd M. Neighoff, Daniel T. Prendergast, Austin Dress, Sean Happel, Karen M. Siegrist, Yale Chang, Johns Hopkins Univ. Applied Physics Lab. (United States)

In order to determine true radiometric quantities in intense fires a three dimensional (3D) understanding of the fire radiometric properties is desirable, e.g., for estimating peak fire temperatures. Imaging pyrometry with a single infrared camera view can provide only two dimensional path-averaged radiometric information. Multiple camera views, however, can form the basis for determining 3D radiometric information such as radiance, emissivity, and temperature. Analytically the fire can be divided into subvolumes in which radiometric properties are assumed roughly constant. Using geometric and thermal equilibrium relationships between the fire subvolumes, together with LWIR camera imagery acquired at multiple carefully defined camera views, radiometric properties of each sub-volume can be estimated. In this work, initial proof-of-principle results were obtained by applying this analysis to sets of LWIR camera imagery acquired during intense (2500 – 3000 K) fires. We present 3D radiance and temperature maps of the fires obtained using this novel approach.

9071-51, Session 12

Protecting IR scene simulators from the dynamics of flight motion simulators

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

A Flight Motion Simulator (FMS) requires a specific configuration to satisfy scene projector specifications. The design of the FMS must carry the IR projector, meet the accuracy, and support the dynamic requirements. In a typical simulator configuration, the high accuracy and high dynamics have conflicting requirements. The high accuracy requires a stiff gimbal design to minimize deflections. The high dynamics require a low inertia, lightweight system to provide high performance. The IRSS design has similar requirements: stiffness, accuracy, and reduced deflections. Increasing the size and weight of the IRSS for the optical considerations, has a negative effect on the axis bandwidth, acceleration, and travel capabilities of existing systems.

Parametric curves are presented of the shock loads to the IRSS in relation to weight and dynamic performance. Relationships are provided to support the basis for the shock absorber design. Recommendations are also provided for the structural integrity for the IRSS design. A compromise in the IRSS design is required as improved structural stiffness and scene complexity increase the weight. Other types of materials are available to reduce weight, but have positive and negative features. A typical set of specifications is presented that can be used as a baseline for the IRSS and motion system design to mitigate shock damage.

9071-52, Session 12

Development and evaluation of technologies for testing infrared imaging sensors

Heard S. Lowry, Sid L. Steely, Ken D. Bynum, Randy A. Nicholson, Aerospace Testing Alliance (United States)

Ground testing of space- and air-borne imaging sensor systems are supported by vis-to-LWIR imaging sensor calibration and characterization, as well as Hardware in the Loop (HWIL) simulaltion with high-fidelity complex scene projection to validate sensor mission performance. To accomplish this successfully, there must be the development and evaluation of technologies that are used in space simulation chambers for such testing, including emitter array cryotesting, silicon carbide mirror cryotesting, and flood source development. This paper provides an overview of such efforts being investigated and implemented at Arnold Engineering Development Complex (AEDC).

9071-53, Session 12

Real-time scene and signature generation for ladar and imaging sensors

Leszek Swierkowski, Chad L. Christie, Leonid Antanovskii, Efthimios T. Gouthas, Defence Science and Technology Organisation (Australia)

A real-time scene generation framework, VIRSuite, has been developed in recent years at the Defence Science and Technology Organisation, Australia, to support hardware-in-the-loop (HWIL) simulation and all-digital test and evaluation of guided weapons. Rapid advances in imaging sensor technologies and their subsequent incorporation into military applications underpin the ongoing development of VIRSuite. The recent improvements in our program enhance its capacity for testing advanced sensors, including those with multi-modal imaging capabilities.

In this paper we report on these latest VIRSuite developments and describe the extension in capabilities that has been achieved. One of the advancements is the development of an improved version of the flash LADAR scene simulation module. The new module is capable of simulating range imagery for both Linear Mode and Geiger Mode LADAR systems. A feature of this module is the simultaneous real-time generation of both range data and IR imagery for a specified spectral band. Another advancement is the significant upgrade to the recently developed dynamic thermal signature prediction module. The module has been provided with a new heat diffusion solver and an advanced and more accurate calculation of heat fluxes. The latest developments preserve all previous features of our scene generation framework and VIRSuite is now capable of generating multi-modal imagery for a wide range of scenarios including air, land and maritime environments. Detailed aspects of the development, performance, capabilities and limitations of the current scene generation system will be presented and discussed.

9071-55, Session 12

Real-time simulation of combined short-wave and long-wave infrared vision on a head-up display

Niklas Peinecke, Sven Schmerwitz, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

Landing under adverse weather conditions can be challenging, even if the airfields are well known to the pilots. This is true for civil as well as military aviation. Within the scope of this paper we concentrate especially on fog conditions. European Union funded project ALICIA brought together partners from industry and research. It was established to build a functional simulation demonstrator for a landing-aid system, especially for landings under foggy weather conditions. Several systems were integrated to help pilots in order to land safely when almost no visual cues are available. Among these systems is a head-up display that can display a generated symbology together with a raster-mode infrared image. We will detail how we implemented a real-time enabled simulation of a combined short-wave and long-wave infrared image for landing on Clermont-Ferrand airport in France, based on open source software. A major challenge was to integrate several already existing simulation solutions, e.g., for visual simulation and sensors with the required data-bases. For the simulations DLR's in-house sensor simulation framework F3S was used, together with a commercially available airport model that had to be heavily modified in order to provide realistic infrared data. Special effort was invested for a realistic impression of runway lighting under foggy conditions. We will present results and sketch further improvements for future simulations.

9071-56, Session 12

Carrier transport in type-II long-wavelength infrared superlattice LEDs and implications for array design

David Westerfeld, Youxi Lin, Sergey Suchalkin, Gela Kipshidze, Takashi Hosoda, Stony Brook Univ. (United States); Boris Laikhtman, Power Photonic Corp. (United States); Leon Shterengas, Gregory Belenky, Stony Brook Univ. (United States)

Three InAs/InGaSb superlattice structures were grown by molecular beam epitaxy on GaSb substrates. Each structure contained two superlattices: a mid-wave infrared (MWIR) structure adjacent to a long-wave infrared (LWIR) structure. The MWIR and LWIR superlattices were similar with the emission wavelength changed by altering the thickness of the InAs layers while the thickness of the $In_{0.25}Ga_{0.75}Sb$ layers was held constant. A p-type InGaSbAs injection layer was grown on one side of the MWIR and LWIR superlattices, while an N-type GaSb barrier was grown on the other side

The three samples differed in the number of periods in the superlattices and also in the arrangement of the superlattice layers. Two of the samples had the MWIR superlattice closer to the n side barrier while the other sample was reversed, with the MWIR superlattice closer to the p side barrier.

The samples were mounted in a liquid nitrogen cryostat and the electroluminescence (EL) and photoluminescence (PL) spectra of the samples were recorded and compared. In the case of PL, carriers were generated largely as a result of absorption in the relatively thick barrier layers. Carriers generated in the barriers are captured in the lower band gap superlattice regions where they thermalize and recombine to produce light. The intense light from the 1.064 μm q-switched Nd:YVO_3 pump laser was expected to reach both barriers, so that excited carriers should be injected into both ends of the superlattice sandwich. In the EL case, holes are injected from one side of the structure and electrons are injected from the other.

The different injection methods produced strikingly different emission spectra. The differences in the EL and PL spectra can be explained by if holes are not able to traverse the superlattice, but electrons can. These results are supported by calculations suggesting that the relatively heavy holes will be less likely to tunnel through their barriers compared to the lighter electrons. This suggests that EL recombination occurs mainly near the p injectors, and that very little light production occurs in the rest of the superlattice.

The energy of LWIR photons is quite low so only a low voltage drop is required across the active region. Cascading multiple superlattices in series brings the total voltage up to a level where it is more easily driven by existing RIIC technologies. The result can be quite a thick structure – each superlattice consists of many layers and these layers are repeated many times. This thick structure can pose problems in array fabrication, as it is necessary to etch deep and narrow trenches to separate the pixels. The finding that the holes are confined near the p-barrier will permit thinner superlattice LEDs which will be easier to process into arrays.

9071-57, Session 12

Ultrahigh-temperature emitter pixel development for scene projectors: performance data

Joseph D. LaVeigne, Santa Barbara Infrared, Inc. (United States)

To meet the needs of high fidelity infrared sensors, under the Ultra High Temperature (UHT) development program, Santa Barbara Infrared Inc. (SBIR) has developed new infrared emitter materials capable of achieving extremely high temperatures. The current state of the art arrays based on the MIRAGE-XL generation of scene projectors is capable of producing imagery with mid-wave infrared (MWIR) apparent temperatures up to 700K with response times of 5 ms. The Test Resource Management Center (TRMC) Test and Evaluation/Science & Technology (T&E/S&T) Program through the U.S. Army Program Executive Office for Simulation, Training and Instrumentations (PEO STRI) has contracted with SBIR and its partners to develop a new resistive array based on these new materials, using a high current Read-In Integrated Circuit (RIIC) capable of achieving higher temperatures as well as faster frame rates. The status of that development will be detailed within this paper, including performance data from prototype pixels.

9071-58, Session 12

Scalable emitter array development for infrared scene projector systems

Joseph D. LaVeigne, Santa Barbara Infrared, Inc. (United States)

Several new technologies have been developed over recent years that make a fundamental change in RIIC architecture possible, which can lead to an operational and cost effective solution for producing large emitter arrays based on the assembly of smaller sub-arrays. Array sizes of 2048x2048 and larger are required to meet the high fidelity test needs of today's modern infrared sensors. The Test Resource Management Center (TRMC) Test and Evaluation/Science & Technology (T&E/S&T) Program through the U.S. Army Program Executive Office for Simulation, Training and Instrumentations (PEO STRI) has contracted with SBIR and its partners to investigate integrating new technologies in order to achieve array sizes much larger than are available today. SBIR and its partners have undertaken several proof-of-concept experiments that lay the groundwork for producing a tiled emitter array. We report on the results of these experiments, including the demonstration of edge connections formed between different ICs with a gap of less than 10μm.

9071-59, Session Posters-Thursday

A novel approach for contrast enhancement of thermal infrared images using quantized local boundary pattern

Gyuhee Park, Yong-Sung Kim, Shichang Joung, SK Telecom (Korea, Republic of)

In this paper, A novel approach for contrast enhancement of thermal infrared images using quantized local boundary pattern is proposed. Enhancing the contrast of an image is very important for image visualization for human visual system. The main issue for this research area is trade off between contrast increasing and noise amplification. Algorithm using global transfer function of an image is suitable for real-time system because of the simplicity for implementation. Unfortunately, it can not be suitable for WDR(Wide Dynamic Range) system. Recently, Various WDR algorithms are proposed to retain the enhancing the global contrast and the loss of local details. But they are required very high complexity and not suitable for real-time system without multi core GPUs integrated server.

Proposed algorithm uses features of QLBP(Quantized Local Boundary Pattern) for enhance the local contrast and prevent the high frequency component dominant effect on histogram domain. Global transfer function is obtained by DRSHE(Dynamic Range Separate Histogram Equalization) which has good result in thermal image. Next process is QLBP map generation of input frame. The QLBP helps to analyze the measurement for enhancing amount. After QLBP map calculation is performed, global transfer function is respectively applied to each pixel using correlation between pixel and QLBP map. Real-time implementation on TI DSP 6446 platform can be achieved by simplified arithmetic operation. To evaluate the algorithm performance, we designed thermal camera based SCD`s VGA LWIR uncooled detector(17um). The experimental results show that proposed algorithm prevented above-mentioned problem and preserved naturalness of an image tha conventional methods. Since contrast between target and background is significantly enhanced without noise amplification, proposed algorithm can be utilized thermal surveillance imaging system such as IRST, EOTS and DVE.

9071-60, Session Posters-Thursday

Background character research for synthetical performance of thermal imaging systems

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Background is assumed to be uniform usually for evaluating the performance of thermal imaging systems, however the effect of background cannot be ignored for target acquisition in reality, background character is important research content for thermal imaging technology. Target Task Performance(TTP) model uses target-to-background contrast Ctgt to describe the effect of background for target acquisition, and can accurately predict system performance with system angle magnification. MRTD Channel Width(MRTD-CW) model proposed by us in recent years had been used to analyze the synthetical performance of thermal imaging systems and obtain system optimal angle magnification. Information quantity NMRTD was used to describe synthetical system performance in MRTD-CW model. In this paper, the effect of background for the synthetical performance was continued to research based on MRTD-CW model. A background noise parameter σ was built in MRTD model and used to describe the background character. A background experiment was designed, and some typical backgrounds(namely grass background, concrete road background, trees background and snow background) noise character were analyzed by σ. MRTD including σ was introduced into MRTD-CW model, the effect of above typical backgrounds for target acquisition were analyzed by MRTD-CW model. NMRTD for different backgrounds was figured out with system angle magnification, and compared with TTP model. Result showed that MRTD-CW model can analyze the effect of background for synthetical performance of thermal imaging system.

9071-61, Session Posters-Thursday

Application of responsivity and noise evaluation method to infrared thermal imaging sensors

Dong-Ik Kim, Ghiseok Kim, Geonhee Kim, Ki-Soo Chang, Korea Basic Science Institute (Korea, Republic of)

In this study, the evaluation method for the responsivity and noise characteristics of a commercial infrared thermal

imaging camera and a custom-made sensor module was presented. Signal transfer functions(SiTFs) and noise equivalent temperature differences(NETDs) of the two sensor modules were obtained by using a differential mode blackbody that is able to control the temperature difference ?T between an infrared target and its background. And we verified the suitability of our evaluation method through the comparison between the found NETD and the specification of the camera. In addition, the difference of 0.01 K of the two noise equivalent temperature differences calculated from with and without nonuniformity correction suggests that the nonuniformity correction is

essential process for the evaluation of the infrared thermal imaging cameras. Finally, in case of the custom-made sensor module, only temporal NETD was found because of its higher nonuniformity characteristics.

9071-63, Session Posters-Thursday

WAHRSIS: a low-cost, high-resolution whole sky imager

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In order to understand and mitigate the effects of clouds on satellite- and other air-to-ground communication links, fine-grained cloud monitoring is required. Traditional methods of use satellite images and radar data. In this work, we present a novel ground-based camera system (a.k.a. whole-sky imagers) as an additional high-resolution source of cloud data. The high cost, low resolution, and complex operation of existing systems has prevented them from widespread deployment. This paper presents a new Whole Sky Imager (WSI) called WAHRSIS (Wide Angle High-Resolution Imaging Sky System) that is designed and developed at the Nanyang Technological University, Singapore. The instrument captures the full 180 degrees field of view within a single picture frame using a circular fish-eye lens and a standard digital single-lens reflex (DSLR) camera with a high-resolution sensor. A sun blocker, used to eliminate the sun glare, is positioned via two stepper motors and an Arduino microcontroller. WAHRSIS uses mainly commodity components and thus can be built at a significantly lower cost (under US$ 3000 for the entire instrument) as compared to other WSIs. Furthermore, unlike expensive multi-spectral imaging systems, WAHRSIS performs a detailed quasi-multi-spectral cloud analysis by removing the conventional IR/UV filter from the DSLR camera, thereby allowing better insights into cloud type and density. The paper will also discuss the geometric and color calibration of the imaging system of WAHRSIS. Initial results indicate the potential for the widespread deployment of such an instrument in many applications, including communication, aviation, weather prediction, or solar irradiation measurement.

9072-1, Session 1

Automatic target recognition for autonomous systems

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The classical paradigm of anomaly detection in images breaks down in cluttered and noisy environments. In this paper we present an "upgraded" and ultimately more robust approach to object detection and classification in sonar images. The classical approach to detection and classification in sonar imagery is match-filtering, followed by edge highlight and shadow estimation, then size estimation for feature extraction. In our approach we replace match-filtering with a weighted highlight-shadow detector; we generate features encompassing both shape and texture; and finally, the classification is performed using a boosted decision tree. The technique is demonstrated on real and synthetic aperture sonar (SAS) imagery.

9072-2, Session 1

Representational learning for object recognition in sonar imagery

Jason C. Isaacs, Naval Surface Warfare Ctr. Panama City Div. (United States)

Learned representations have been shown to give promising results for solving a multitude of novel learning tasks, even though these tasks may be unknown when the generative model is being trained. A few notable examples include learning of Topic Models, Deep Belief Networks, Deep Boltzmann Machines, and Local Discriminative Gaussians inspired by human learning. This self-learning of new concepts via rich generative models has emerged as a promising area of research in machine learning. Although there has been recent progress, existing computational models are still far from being able to represent, identify and learn the wide variety of possible patterns and structure in real-world data. An important issue for further consideration is the use of unsupervised representations for novel target recognition applications. This work will discuss and demonstrate the use of auto-encoders for learning discriminating representations of objects in sonar imagery. The objective is to make these representations more abstract and invariant to noise in the training distribution and improve performance.

9072-3, Session 1

Coherent change detection technique for synthetic aperture sonar

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Automatic Change Detection (ACD) compares new and stored terrain images for alerting to changes occurring over time. For image correlation ACD to reliably detect the appearance of small man-made objects in sonar imagery, the background of two scenes being compared must quantitatively be similar. Synthetic aperture sonars (SAS)–coherent sensors that produce fine-scale, range-independent resolution seafloor images–are well suited for this approach. Sources of degradation in inter-scene coherence include system imperfections, changes in the scene between imaging events, and decorrelation due to variations in viewing geometry–termed baseline or spatial decorrelation. In CCD the phase difference between two images acquired from slightly different positions or times are analyzed. These images are acquired on two different SAS passes with relative geometry. The phase coherence and the image correlation are estimated over the spatial kernel, and can be used to detect changes that are placed on the bottom of water surface.

This paper describes an implementation of automated change detection (ACD), where reference and repeat-pass images are geographically co-registered onto a single grid for CCD.

9072-4, Session 1

Feature-based recognition of submerged objects in holographic imagery

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The ability to autonomously sense and characterize underwater objects in situ is desirable in application areas utilizing unmanned underwater vehicles (UUVs). These applications may include remediation of mines, unexploded ordnance, or hazardous materials. In this work, underwater object recognition was explored using a digital holographic system. Holographic systems provide the potential for reduced size, weight, and power requirements as compared to conventional imaging approaches. In this work, a preliminary experiment was performed in which several objects of varying size, shape, and material were submerged in a 43,000 gallon test tank. Holograms were collected from each object at multiple distances and orientations, with the imager located either outside the tank (looking through a porthole) or submerged (looking downward). The resultant imagery from these holograms was preprocessed to improve dynamic range, mitigate speckle, and segment out the image of the object. A collection of feature descriptors were then extracted from the imagery to characterize various object properties (e.g., shape, reflectivity, texture). The features extracted from images of multiple objects, collected at different imaging geometries, were then used to train statistical models for object recognition tasks. The resulting classification and regression models were used to perform object classification as well as estimation of various parameters of the imaging geometry. Results of applying these models in cross-validation indicate that certain queries may be dependent upon the outcomes of others, and these observations should be considered in development of future autonomous sensing algorithms for UUVs employing holographic imagers.

9072-5, Session 1

Target identification using synthetic aperture acoustics

Mary Knox, Stacy Tantum, Leslie M. Collins, Duke Univ. (United States)

Synthetic aperture acoustic (SAA) imaging is an effective method for locating surface-laid objects in a spatial scene. SAA-based imaging methods are relatively inexpensive, with respect to both necessary equipment and computational requirements, and potentially provide complementary information to other spatial scene sensors, including ground penetrating radar. In this work, the SAA system consists of a speaker to generate acoustic signals aimed at the ground surface and a microphone to record the acoustic reflections off of the ground and surface-laid objects. The transmitted acoustic signal is a 10 millisecond chirp from 2 kHz to 16 kHz, repeated 25 times per second. The goal of this work is to distinguish between three types of surface-laid objects -- jagged rocks, river rocks, and concave capped cylinders -- from the SAA information. All three objects exhibit similarly shaped strong acoustic reflections in the time domain. Since there is significant similarity in the time domain responses from the three objects, the frequency domain responses are investigated for identifying them. More specifically, features based on the distribution of energy across frequency (2 kHz to 16 kHz) are extracted from the microphone recording.

Experimental results show that the three objects are distinguishable according to these frequency domain features. Additional features are also considered.

9072-6, Session 2

Digital shearography as a ground vibration sensor for acoustic detection of buried mines

Vyacheslav Aranchuk, Ina Aranchuk, James M. Sabatier, Univ. of Mississippi (United States)

Acoustic detection of buried mines has proved itself as a technique that provides high probability of detection and very low false alarm rate. The method consists of exciting ground vibrations and measuring the vibration characteristics of the ground at many points with a laser Doppler vibrometer (LDV). While LDVs can provide vibration measurements of the ground with sub-nanometer sensitivity, their performance is affected by the platform motion. As a result, field applications of LDVs require operation from a mechanically stable platform, or compensation for the platform motion. This paper investigates application of digital shearography as an alternative technique for ground vibration sensing in acoustic detection of buried mines. Digital shearography is a laser interferometric technique that measures difference in displacement between corresponding points in an image of the object and its sheared copy. Due to the lack of the reference beam it has low sensitivity to platform motion. This feature along with high spatial resolution makes shearography an attractive technique for acoustic detection of buried mines and IEDs. In this work the ability of shearography to measure vibration signatures of buried mines has been investigated. Experimental results on sensitivity of shearography for detection of buried mines and spatial characteristics of shearograms of buried mines are presented and discussed in the paper.

9072-7, Session 2

Exploiting spatial and phase correlations for seismic mine detection

Jordan M. Malof, Mary Knox, Peter A. Torrione, Leslie M. Collins, Kenneth D. Morton Jr., Duke Univ. (United States)

Seismic mine detection has been experimentally validated as a means to detect buried threats at greater standoff distances than many other technologies for subsurface detection. One approach to seismic based mine detection utilizes surface vibrational measurements from a laser vibrometer and a known stimulus acoustic signal in order to characterize the acoustic-to-seismic coupling ratio of the earth, which is altered by the presence of a landmine. Recent investigations into the efficacy of seismic mine detection using traditional techniques have indicated that detection performance drops when the surface of the ground is disturbed. This is a routine condition in the field and therefore presents problems for practical acoustic detection systems. The first part of this work undertakes a baseline evaluation and comparison of established algorithms and human performance. Performance is evaluated on laser vibrometer measurements taken under both pristine and disturbed soil conditions in order to evaluate the impact of disturbed earth. It is shown that humans presented with visual representations of the data are capable of discriminating between targets and non-targets better than current algorithms, particularly when the ground surface is disturbed. The second part of this work explores new features for seismic mine detection that exploit the spatial and phase correlations that are currently unexploited by established methods. The developed methods are shown to provide additional information and thus improve performance when combined with established features, resulting in performance closer to that obtained by human visual inspection.

9072-8, Session 3

High to very high-frequency metal/anomaly detector

Daniel C. Heinz, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States); Michael L. Brennan, CACI International Inc. (United States); Michael B. Steer, North Carolina State Univ. (United States); Adam W. Melber, John T. Cua, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States)

Typical metal detectors work at very low to low frequencies. In this paper a metal/anomaly detector design that operates in the high to very high frequency range is presented. This design uses a high-Q tuned loop antenna for metal/anomaly detection. By measuring the return loss or voltage standing wave ratio a frequency notch can be detected. Tuning to the optimal location of the notch can be accomplished by monitoring the phase response. This phase monitoring technique can be used to ground balance the detector. As a metal object is moved along the longitudinal axis of the loop antenna a substantial shift in the frequency of the notch is detected. For metal targets the frequency shift is substantially higher. For ferrite and other targets the frequency shift is substantially lower. This frequency shift is created by the proximity of the target causing a change in the impedance of the antenna. Experiments with a prototype antenna show detection is very good at long detection ranges and with very low power requirements. The detector requires only one loop with one winding which is used for both transmit and receive. This allows for a metal/anomaly detector with a very simple design. This simple design with a single wire shall be lightweight and depending on loop size – may significantly increase detection depth performance. In the full paper, modeling and further experimental results will be presented. Performance results for various types of soil and for different types of targets will be shown.

9072-9, Session 3

Homemade explosives in the subsurface as intermediate electrical conductivity materials: a new physical principle for their detection

Steven A. Grant, Benjamin E. Barrowes, Steven A. Arcone, U.S. Army Engineer Research and Development Ctr. (United States)

Detection of homemade explosive (HME) containing ammonium nitrate (AN) in the subsurface is of great interest to the US military and its coalition partners. Due to the hygroscopy of AN, this HME is expected to be an intermediate electrical conductivity material (IECM), defined here as one having electrical conductivity greater than soils, which have conductivities 0.1 to 1000 mS/m, but less than metals, which have electrical conductivities on the order of 10 MS/m. Our preliminary experimental and numerical modeling have established that AN-containing HME in the subsurface can, in all likelihood, be detected by electromagnetic exploration geophysics techniques, specifically by ground penetrating radar (GPR) and by electromagnetic induction (EMI). The electromagnetic induction signatures of HME for these techniques are distinctive. For example, in the case of EMI, the maximum quadrature response frequencies for IECM targets have been found to be greater than 100 kHz.

9072-10, Session 3

The magnetic polarizability of thin shells

Jonathan E. Gabbay, Waymond R. Scott Jr., Georgia Institute of Technology (United States)

The ability to detect and dispose of buried hazards requires effective means by which to discriminate between hazardous targets and benign clutter. In that regard, wideband Electromagnetic Induction (EMI) sensors have shown

significant promise in their ability to classify buried metallic objects based on their response to illumination by a time-varying magnetic field. This follows primarily from the observation that a target's EMI response, at least partially, provides an indication to a target's shape and size. Additionally, the response varies predictably with a change in a target's orientation.

A target's EMI response can be expressed compactly in its magnetic polarizability dyadic, a form that describes the reaction of a scatterer to an arbitrary magnetic field. The work in this paper decomposes the magnetic polarizability dyadic using Baum's singularity expansion method, by which the dyadic may be expressed as an expansion of a series of decaying current modes.

The target response is computed for thin conducting shells using a Method of Moments (MoM) approach, where the two-dimensional current density is expressed using a stream function. The singularity expansion is then computed through an eigenvalue decomposition of the MoM matrix. The eigenvalue decomposition produces the eddy current modes supported by the target along with their relaxation frequencies which are then related to the singularity expansion.

Using this approach, the singularity expansion of different classes of targets will be studied. Empirical formulas and observations that describe the behavior of the modes will be provided when possible.

9072-11, Session 3

Experimental detection and discrimination of buried targets using an improved broadband CW electromagnetic induction sensor

Waymond R. Scott Jr., Gregg D. Larson, Georgia Institute of Technology (United States)

Experimental results from field testing of an improved version of the Georgia Tech EMI system that has been under development for the past several years are presented. The system has improved accuracy and sensitivity while being more power efficient than earlier systems. The accuracy improvements are obtained by improved shielding while the sensitivity improvements are obtained with improved preamplifiers. A switched-mode power amplifier is used to improve the power efficiency without degrading the performance.

Methods and features that can be used to separate the response of metallic targets from the soil response are presented. These include parameters related to the logarithmic soil model and other parameters related to the phase of the soil response. When a target is present, the shape of the measured response has been shown to be a good feature for discrimination between certain classes of metallic targets; however, this feature is degraded when the soil response is comparable to the target response. Methods for dealing with this mixed response by removing the logarithmic soil model are presented. Data from the field test will be used to demonstrate the viability of these methods and the relative performance of the features will be shown.

9072-12, Session 3

Implementation of optimized electromagnetic induction coils

Mark A. Reed, Waymond R. Scott Jr., Georgia Institute of Technology (United States)

Continuous-wave electromagnetic induction systems generally use separate transmit and receive coils. These coils are usually wound to minimize the mutual coupling between the coils. However, the winding methods used to minimize the coupling either reduce the depth performance of the system or make the coils poorly compatible with a ground penetrating radar (GPR). A method of optimizing a pair of coils that significantly lessens these limitations was previously presented, but implementation of the original optimized coils presents practical issues, often as a result of mechanical constraints. Therefore, a new set of hybrid coils is optimized and implemented, and the optimization and design methods explained. In this new set, the receive coil is manufactured on a PCB, and the transmit coil is wire wound on a composite form. These new coils address many of the problems encountered with the initial coils, such as difficulty in coil spacing, low inductance, high transmit resistance, and uneven heating that led to drift. Proper spacing of the coils is very important to obtaining a low coupling factor, so an improved method of spacing and then permanently fastening the coils together is developed. Permanently fastening the coils permits improved coil characterization, including coil coupling and field patterns. The results of the characterization are then shown.

9072-13, Session 4

Optimizing electromagnetic induction sensors for dynamic munitions classification surveys

Jonathan S. Miller, Gregory Schultz, White River Technologies, Inc. (United States)

The prevalence of innocuous clutter at munitions response sites presents a challenge to remediation efforts that often devote substantial resources to the excavation and identification of these non-hazardous objects. Recent development of advanced electromagnetic induction (EMI) sensor arrays that enable multi-axis illumination of magnetic anomalies has enabled the implementation of methodologies that effectively discriminate clutter from unexploded ordnance (UXO) or other munitions and explosives of concern (MEC). Currently, standard protocol for detection and classification of MEC comprises a two-step process that includes an initial low resolution dynamic EMI survey to detect magnetic field anomalies associated with potential threats followed by a higher resolution static EMI survey that enables classification of these anomalies. While this approach has demonstrated significant success in producing effective classification of UXO, conducting two successive surveys is time consuming. Additionally, target picking based on analysis of low resolution EMI data can lead to ineffective placement of the classification sensor during the follow-up cued survey. An alternative method is to employ sensors that enable detection and classification from data collected during a single dynamic survey. This one-pass approach requires sensors that feature several unique attributes, including effective multi-axis illumination across the full sensor swath. We present data and test results from an advanced EMI sensor optimized for one-pass surveys. We demonstrate how tradeoffs between spatial sampling resolution, positioning accuracy, and time decay sampling affect the classification quality of the data. We also present design considerations that produce optimal transmitter and receiver configurations for these dynamic classification surveys.

9072-14, Session 4

Automatic classification of unexploded ordnance applied to live sites for MetalMapper sensor

Johnny B. Sigman, Benjamin E. Barrowes, Kevin A. O'Neill, Yinlin Wang, Fridon Shubitidze, Dartmouth College (United States)

This paper examines a previously introduced method for automatic classification of Unexploded Ordnance (UXO) across several datasets from live sites. The sensor used was the MetalMapper, a time-domain Electromagnetic Induction (EMI) sensor, with 3 orthogonal transmitters and 7 separate 3-axis receiver cubes. Each transmitter is activated sequentially, and magnetic field is recorded on all receivers. From the sensor data, extrinsic and intrinsic parameters are determined using the Differential Evolution (DE) and Ortho-Normalized Volume Magnetic Source (ONVMS) algorithms, respectively. The inversion provides spatial locations and intrinsic time-series total ONVMS principal eigenvalues. These are fit to a power-decay empirical model, the Pasion-Oldenburg model, providing dimensionality reduction to 3 coefficients (k, b, and g) for each object. The anomalies are grouped using the unsupervised clustering Weighted-Pair Group Method with Averaging (WPGMA) algorithm. Central elements of

each cluster are dug, and the results are used to train the next round of dig requests. A Gaussian Mixture Model (GMM) was used for our supervised learning algorithm, in which a multivariate Gaussian probability density represents each class of UXO in the feature space. We request ground truths for anomalies in rounds, until there are no more Targets of Interest (TOI) in consecutive requests. Results of the studies are demonstrated and analyzed.

9072-15, Session 4

A combined joint diagonalization: MUSIC algorithm for subsurface targets localization

Yinlin Wang, Johnny B. Sigman, Thayer School of Engineering at Dartmouth (United States); Benjamin E. Barrowes, Kevin A. O'Neill, Thayer School of Engineering at Dartmouth (United States) and U.S. Army Engineer Research and Development Ctr. (United States); Fridon Shubitidze, Thayer School of Engineering at Dartmouth (United States) and Sky Research, Inc. (United States)

This paper presents a combined joint diagonalization (JD) and multiple signal classification (MUSIC) algorithm for estimating subsurface objects locations from electromagnetic induction (EMI) sensor data, without solving ill-posed inverse-scattering problems. JD is a numerical technique that finds the common eigenvectors that diagonalize the set of multistatic response (MSR) matrices measured by the time-domain EMI sensor. Eigenvectors from targets of interest (TOI) can be then distinguished from noise-related ones, as shown in previous studies. Filtering is also carried out in JD to improve signal-to-noise ratio (SNR) of the data. The MUSIC algorithm utilizes the orthogonality between signal and noise subspaces in MSR matrix, which can be separated with information provided by JD. An array of theoretically-calculated Green's functions are then projected onto the noise subspace, and the location is estimated by the minimum owing to the orthogonality. This combined method is applied to data of the Time-Domain Electromagnetic Multisensor Towed Array Detection System (TEMTADS), which is a 5x5 array of concentric transmitter/receiver pairs. Examples of TEMTADS test stand data and field data collected at Spencer Range, Tennessee are analyzed and presented. The studies show that due to its non-iterative mechanism, the method can be executed fast enough to provide real-time estimation of object location in the field from survey data sets.

9072-16, Session 5

Acquisition and processing of advanced sensor data for ERW and UXO detection and classification

Gregory Schultz, Joe Keranen, White River Technologies, Inc. (United States); Zeke Topolosky, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Jonathan S. Miller, White River Technologies, Inc. (United States)

Remediation of explosive remnants of war (ERW) and associated unexploded ordnance (UXO) has seen improvements through the injection of modern technological advances and streamlined standard operating procedures. However, reliable and cost-effective detection and geophysical mapping of sites contaminated with ordnance such as cluster munitions, abandoned weapons, and improvised explosive devices rely on the ability to discriminate hazardous items from metallic clutter. In addition to anthropogenic clutter, handheld and vehicle-based metal detector systems are plagued by natural geologic and environmental noise in many post conflict areas. We present new and advanced electromagnetic induction (EMI) technologies including man-portable and towed EMI array data acquisition software and processing algorithms. While these systems feature vastly different form factors and transmit-receive configurations, they all exhibit several fundamental traits that enable successful feature classification of EMI anomalies. Specifically, multi-directional sampling of scattered fields from targets and corresponding high volume of unique data provide a rich information for extracting useful classification features for clutter rejection analysis. The quality of classification features and success of discrimination algorithms depend largely on the extent to which the data resolve unique physics-based parameters. To date, most of the advanced sensors enable high quality inversion by producing data that are extremely rich in spatial content through multi-angle illumination and multi-point reception.

9072-17, Session 5

Detecting and classifying small and deep targets using improved EMI hardware and data processing approach

Fridon Shubitidze, Dartmouth College (United States); Benjamin E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); Johnny B. Sigman, Yinlin Wang, Dartmouth College (United States); Irma Shamatava, White River Technology, Inc. (United States); Kevin A. O'Neill, Dartmouth College (United States)

The appearance of next-generation EMI sensors has been accompanied by the development of advanced EMI models and new interpretation and inversion schemes that take advantage of the richness and diversity of the data provided by these instruments. The technologies have been successfully tested in various scenarios, including ESTCP live-UXO classification studies, and have demonstrated superb classification performances. One of such sensors is 2x2 3d TEMTADS. The instrument consists of 4 transmit square loops and four vector receive sensors a 2 x 2 grid. The sensor activates the transmitter loops in sequence, one at a time, and for each transmitter all receivers measure the complete transient response over a wide dynamic range of time. Thus, in cued interrogation mode the sensor provides a total of 4x3x4=48 high-fidelity data at each instrument location. The studies have showed, that the system's ability to detect and classify small targets (i.e., with calibers ranging from 20 to 60 mm) and deep targets (burial depth more than 11 times targets diameter) till is a challenging problem using a standard detection approach. In order to overcome this problem, in this work , the standard approach is replaced with the joint diagonalization technique. Namely, first multi static response data (MSRD) is created by using different combinations of Tx coils, then the joint diagonalization technique is applied to MSRD matrix, eigenvalues are extracted and used for targets detection. Finally, to improve targets classification the Tx currents magnitudes are increased from 6 Amperes to 14 Amperes, and targets parameters are extracted using the ortho-normalized volume magnetic source technique. Studies are done for a 37mm projectile placed at 42cm, 68 cm and 86 cm under the 2x2 TEMTADS instrument. The targets detection and classification performances are illustrated for 6 Ampere and 14 Ampere Tx currents

9072-18, Session 5

Advanced EMI models for survey data processing: targets detection and classification

Fridon Shubitidze, Dartmouth College (United States); Benjamin E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); Irma Shamatava, White River Technology, Inc. (United States); Johnny B. Sigman, Yinlin Wang, Kevin A. O'Neill, Dartmouth College (United States)

One of the most challenging aspects of survey data processing is target picking. The fundamental input for the classification is dynamic data collected along survey lines. These data are different from the static data obtained in cued mode and used for target classification. Survey data are typically collected using just one transmitter loop (the Z-axis loop) and feature short data-point collection times and short decay-transient times. The collection intervals for each data point are typically 0.1 s, and the signal

repetition rates are typically 90 or 270 Hz (in other words, the transient decay times are 2.7 ms or 0.9 ms). Reliable classification requires multiple side/angle illumination; i.e., to conduct reliable classification it is necessary to combine and jointly invert multiple data points. However, picking the data points that provide the optimal information for classifying targets is a difficult task. The traditional method plots signal amplitudes on a 2D map and picks peaks of signal level without properly accounting for the underlying physics. In this paper, the joint diagonalization is applied to survey data sets to improve data pre-processing and target picking. The JD technique is an EMI data analysis and target classification technique and is applicable for all next-generation multi-static array EMI sensors. The method extracts multi-static response data matrix eigenvalues. The eigenvalues are main characteristics of the data. Recent studies have demonstrated that the method has great potential to quickly estimate the number of potential targets and moreover classify these targets at the data-pre-processing stage, in real time and without the need for a forward model. Another advantage of JD is that it provides the ability to separate signal from noise making it possible to de-noise data without distorting the signal due to the targets. In this paper the JD technique is used to process dynamic data collected at South West Proving Ground using the 2 x 2 TEMTADS system. The joint eigenvalues are extracted as functions of time for each data point and summed/stacked them together, and used for creating detection maps. Once targets are detecting then a set of data are chosen for each anomalies and inverted using the ortho-normalized volume magnetic source technique. The detection and classification results are demonstrated

9072-19, Session 5

Multichannel transmit/receive metal detector coil array for vehicular applications

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Metal detector coil design has been matured to great extent over the years. However, vehicle mounted or remotely operated metal detectors require different specifications and these specifications dictate multiple transmit and receive coils operating in various settings. Unlike handheld operation, detector is more susceptible to metallic body of the vehicle. Moreover, ground calibration is also different than handheld devices. Coil geometries and intercoupling between them play a significant role in system design and performance. In this study, we present analytical and numerical simulations of proposed coil geometries. Time gating, coil coupling, and coil-to-GPR antenna coupling are analyzed in terms of performance metrics. Experimental data will also be presented for the proposed geometries.

9072-20, Session 5

Geometric approach of planar spiral mono-coil design to maximize the detection range of time-domain electromagnetic induction landmine detector

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This paper investigates the variation of the detection range of mono-coil electromagnetic induction (EMI) landmine detector as the geometry of the search coil is varied. The coil geometry considered in this paper is planar square spiral coils with a fixed outer side length of 45 cm. The side length of the inner square and the spacing between the wires are varied.

Static magnetic field distributions induced by the coils are simulated using the finite element method (FEM) to study the effect of the geometric variations. The coils are also fabricated on an FR-4 printed circuit board (PCB) and applied to a typical time domain EMI landmine detector as a search coil. For each coil configuration, the detection range for subsurface metallic landmines are measured and compared to the simulated magnetic field strengths. The experimental results are consistent with the predictions made by the field simulation.

It is demonstrated that the coil geometries with smaller inner side lengths and trace spacing have deeper detection ranges. The fields generated by the coil with smaller inner side lengths are shown to be larger and more concentrated at a close distance than the coils with larger inner side lengths. Thus, the coil with a small inner side length can have a high sensitivity for small targets near the ground surface, which may be missed by coils with large inner side lengths.

9072-21, Session 6

Experiment design for measuring the probability of detection in remote sensing: How many objects? How many passes?

Peter A. Torrione, Leslie M. Collins, Kenneth D. Morton Jr., Duke Univ. (United States)

Buried threat detection system (e.g., GPR, FLIR, EMI) performance can be summarized through two related statistics: the probability of detection (PD), and the false alarm rate (FAR). These statistics impact system rate of forward advance, clearance probability, and the overall usefulness of the system. Understanding system PD and FAR for each target type of interest is fundamental to making informed decisions regarding system procurement and deployment. Since PD and FAR cannot be measured directly, proper experiment design is required to ensure that estimates of PD and FAR are accurate. Given an unlimited number of target emplacements, estimating PD is straightforward. However in realistic scenarios with constrained budgets, limited experiment collection time and space, and limited number of targets, estimating PD becomes significantly more complicated. For example, it may be less expensive to collect data over the same exact target emplacement multiple times than to collect once over multiple unique target emplacements. Clearly there is a difference between the quantity and value of the information obtained from these two experiments (one collection over multiple objects, and multiple collections over one particular object). This work will clarify and quantify the amount of information gained from multiple passes over one target compared to collecting over multiple unique target burials. Results provide a closed-form solution to estimating the relative value of collecting multiple times over one object, or emplacing a new object, as well as numerical simulations to evaluate the impact on estimates of probability of detection.

9072-22, Session 6

Improved resistive-vee dipole-based arbitrary polarization antenna system for ground penetrating radar

James W. Sustman, Waymond R. Scott Jr., Georgia Institute of Technology (United States)

A broadband arbitrary polarization antenna system for ground penetrating radar applications has been improved. The antenna system uses four, crossed, resistive-vee dipole (RVD) antennas operating bistaticly to measure the simultaneous transmission and reception of multiple polarizations. The RVD has low self clutter, low radar cross section and wideband performance. The RVD is a linearly polarized antenna, but other polarizations can be synthesized through the use of two orthogonal RVDs to transmit or receive orthogonal field components. The antenna system is able to distinguish rotationally symmetric and linear targets with its ability to transmit and receive both senses of circular polarization. For example, linear targets such as wires or pipes can be identified by even scattering of both senses of circular polarization. The RVDs in the previous RVD-based CP (circularly

polarized) antenna were not designed for CP synthesis. The shape and resistive profile of the RVD were modified to improve dual CP performance. The design of the RVD was optimized through simulation to improve CP synthesis and forward gain, while maintaining low self clutter, low radar cross section, and wide bandwidth. Additional simulations demonstrate that the improvements to the RVD make it easier to correctly discriminate targets based on their geometries.

9072-23, Session 6

Comparison of ring resonator relative permittivity measurements to GPR data

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Field experience has shown that soil conditions can have large effects on Ground Penetrating Radar (GPR) detection of buried targets of interest. The relative permittivity of the soil determines the attenuation of the radar signal. The contrast between the relative permittivity of the soil and the target is critical in determining the strength of the reflection from the target. In this paper, a microstrip ring resonator is used to measure the relative permittivity of the soil and various target fill materials. For this measurement technique, a microstrip ring resonator is placed in contact with a material medium and the real and imaginary parts of the relative permittivity are determined from changes in resonant frequencies (between 600 MHz and 2 GHz) and the quality factor of the resonator, respectively. Measurement results are compared to data collected by a GPR.

9072-24, Session 6

Physics-based deformations of ground penetrating radar signals to improve the detection of buried explosives

Rayn T. Sakaguchi, Kenneth D. Morton Jr., Leslie M. Collins, Peter A. Torrione, Duke Univ. (United States)

A number of recent algorithms have shown improved performance in detecting buried explosive threats by statistically modelling target responses observed in ground penetrating radar (GPR) signals. These methods extract features from known examples of target responses to train a statistical classifier. The statistical classifiers are then used to identify targets emplaced in previously unseen conditions. Due to the variation in target GPR responses caused by factors such as differing soil conditions, classifiers require training on a large, varied dataset to encompass the signal variation expected in operational conditions. These training collections generally involve burying each target type in a number of soil conditions, at a number of burial depths. The cost associated with both burying the targets, and collecting the data is extremely high. Thus, the conditions and depths sampled cover only a subset of possible scenarios. The goal of this research is to improve the ability of a classifier to generalize to new conditions by deforming target responses in accordance with the physical properties of GPR signals. These signal deformations can simulate a target response under different conditions than those represented in the data collection. This research shows that improved detection performance in previously unseen conditions can be achieved by utilizing deformations, even when the training dataset is limited.

9072-25, Session 6

Target localization and signature extraction in GPR data using expectation-maximization and principal component analysis

Daniel Reichman, Kenneth D. Morton Jr., Peter A. Torrione, Leslie M. Collins, Duke Univ. (United States)

Ground Penetrating Radar (GPR) is a very promising technology for subsurface threat detection. A successful algorithm employing GPR should achieve high detection rates at a low false-alarm rate and do so at operationally relevant speeds. GPRs measure reflections at dielectric boundaries which occur at the interfaces between different materials. These boundaries may occur at any depth, within the sensor's range, and furthermore, the dielectric constants could be such that they induce a 180 degree phase shift in the received signal. As a result of these time-of-arrival and phase variations, extracting features from target responses in GPR is not straightforward. In this work, a method to mitigate polarity and alignment variations based on an expectation-maximization (EM) principal-component analysis (PCA) approach is proposed. This work shows how model-based target localization can significantly improve performance. Performance is measured according to the improvement in the ROC for classification before and after the data is properly aligned and phase-corrected.

9072-26, Session 7

A robust Bayesian approach to target detection applied to explosive threat detection in handheld ground penetrating radar data

Kenneth D. Morton Jr., Leslie M. Collins, Peter A. Torrione, Duke Univ. (United States)

Target detection algorithms for ground penetrating radar (GPR) data typically calculate local statistics for the background data surrounding a test sample as a means to assess changes in the data from background. To ensure that the local statistics are indicative of only the background data and not the data due to a potential target, a guard-band is employed to prohibit the data near the test sample from being used in the calculations. The selection of the guard-band can greatly impact performance, and the value chosen should be based on the expected size of a target response, a challenging task when the target population varies greatly. This work develops a robust Bayesian approach to target detection that does not require selection of a guard-band. By modeling the data using Student's-T distribution rather than a Gaussian distribution, an inference algorithm is developed that automatically identifies outliers from the background and excludes them while calculating the local statistics. The algorithm that was developed is applied to handheld GPR data, where it is shown to provide improved performance over any particular selection of a guard-band when the size of targets varies due to either a diverse target population or uncertain spatial sampling in the data.

9072-27, Session 7

Change detection using down-looking ground-penetrating radar

Erik Rosen, Marie Fishel, Elizabeth Ayers, Phillip Koehn, Institute for Defense Analyses (United States)

Down-looking ground penetrating radar (DLGPR) has been used extensively for buried target detection. For operational implementations, the sensor is used in direct detection mode, where algorithms process data while passing over targets, and decisions are made before a system has overpassed the target. Change detection differs by utilizing passes over lanes and roadways prior to target burial. Change detection performance can improve upon direct detection performance by comparing current data with prior data, but it also has inherent operational limitations. Performance enhancements can include the mitigation of anomalies not associated with targets, as well as increased detection probabilities of deeper targets through indirect means. In the latter case, deep buried targets that do not appear in the GPR data can be indirectly detected using change detection methods, if the patch of ground where the target is buried has been significantly modified from its original undisturbed state. In this paper, we explore decision-based and image-based change detection approaches for enhancing the performance of a DL GPR system, and enumerate the limitations of the approach.

9072-28, Session 7

Analysis of variance (ANOVA) using down-looking ground-penetrating radar data

Erik Rosen, Marie Fishel, Phillip Koehn, Institute for Defense Analyses (United States)

Down-looking ground penetrating radar (DLGPR) has been used extensively for buried target detection. Data collected over the years by one system in particular allows for the study of the dependence of detection performance on target dependent factors such as target type, metallic content, and burial depth, as well as environmental and testing factors that may influence detection such as direction of travel, soil types, soil moisture content, and other testing conditions. In this paper, we analyze GPR data collected over targets using Analysis of Variance (ANOVA) techniques. ANOVA provides a straightforward statistical method for determining whether one or more factors affect the response of the system under study. For our purposes, the system response is not the detection probability, but is instead the algorithm(s) output of the GPR detector, or more fundamentally, the magnitude of the peak signal over the target. Based on the results of the ANOVA analysis, we make recommendations for future data collections using basic principles of Design of Experiments (DOE).

9072-29, Session 7

Context-dependent multiple kernel learning for explosive hazards detection in forward-looking ground-penetrating radar

John Becker, Timothy C. Havens, Timothy J. Schulz, Michigan Technological Univ. (United States)

The main challenge in detecting explosive hazards with FLGPR is that there are multiple types of targets buried at different depths in a highly-cluttered and highly-variable background environment. A vast array of target, clutter signatures, and local site conditions exist, which makes the design of effective detection algorithm difficult, especially of those algorithms based on physics-based models. Recent work in this application has focused on machine learning-based fusion methods, including fusion of multiple modalities of sensors (e.g., FLGPR and infrared), fusion of multiple frequency sub-band images in FLGPR, and feature-level fusion using multiple kernel learning (MKL). For this paper, we will develop automatic methods for choosing optimal kernel combinations for disparate locations in the operational environment. In essence, the algorithm automatically selects from a code-book of learners, each tuned to a different type of overall target condition. Using FLGPR data collected at a US Army test site, we will compare the performance of several methods for automatic tuning of MKL detection schemes to localized contexts.

9072-30, Session 7

Hyperbolic and PLSDA filter algorithms to detect buried threats in GPR data

Dmitry Kalika, Kenneth D. Morton Jr., Leslie M. Collins, Peter A. Torrione, Duke Univ. (United States)

Ground Penetrating radar (GPR) is a commonly used modality for the detection of buried threats. This work explores two approaches for buried threat detection in GPR data that we refer to as the hyperbolic filter and PLSDA filter algorithms. The hyperbolic filter algorithm leverages the hyperbolic shape of buried threat GPR responses, while the PLSDA algorithm uses a PLSDA linear classifier to learn a filter based on classifier weights. A hyperbolic filter is trained and optimized by doing a grid search over a set of hyperbola parameters. The PLSDA filter is generated by aligning GPR data and training PLSDA weights on that feature space. The correlation between each filter and the 2D GPR data provides information regarding the presence of buried threats. The PLSDA and hyperbolic filters were generated for a data set containing multiple target types. Both PLSDA and hyperbolic filters outperformed a prescreener for target subsets, and performed similarly over all target types. Relative to one another, both PLSDA and hyperbolic filters performed equally well. PLSDA filters, however, can be trained much faster than the corresponding hyperbolic filter exhaustive search.

9072-31, Session 8

Fusion of multiple algorithms for detecting buried objects using fuzzy inference

Hichem Frigui, Amine B. Khalifa, Univ. of Louisville (United States)

We present a fusion method, based on fuzzy inference, for detecting buried objects using ground-penetrating radar (GPR) data. The GPR sensor generates 3-dimensional data that correspond to depth, down-track, and cross-track. Most discrimination algorithms process only 2-D slices of the 3-D cube: (down-track, depth) or (cross-track, depth). The performance of the down-track and cross-track discrimination algorithms can vary significantly depending on the target shape, burial orientation, and other environmental conditions. In some cases, these algorithms can provide complimentary evidence, while in other cases they provide contradicting evidence. Thus, effective fusion of these algorithms can achieve higher probability of detection with fewer false alarms.

The proposed fusion method is capable of learning meaningful and simple fuzzy rules for different regions of the input space generated by partial confidence values of the different discriminators. To learn the rules, first, the input space is partitioned to identify local contexts. Second, input membership functions are learned based on the statistics of the partial confidence values of the individual discriminators within each context. Third, output membership functions are generated by considering the distributions of targets and non-targets within each context as well as additional background information. Finally, the input and output membership functions are combined into a Mamdani-type fuzzy inference system. The output of the learning process is a fuzzy rule base adapted for different contexts.

Results on large and diverse GPR data collections show that the proposed fusion approach can identify local, simple, and meaningful rules capable of non-linear fusion of different discriminators. We also show that the proposed fuzzy inference outperforms commonly used fusion methods.

9072-32, Session 8

Fusion of forward-looking infrared and ground-penetrating radar for improved stopping distances in landmine detection

Jordan M. Malof, Kenneth D. Morton Jr., Leslie M. Collins, Peter A. Torrione, Duke Univ. (United States)

Ground penetrating radar (GPR) is a popular sensing modality for buried threat detection that offers low false alarm rates (FARs), but suffers from a short detection stopping distance. This short stopping distance leaves little time for the system operator to react when a threat is detected, limiting the speed of advance. This problem arises, in part, because of the way GPR data is typically processed. GPR data is first prescreened to reduce the volume of data considered for higher level feature-processing. Although fast, prescreening introduces latency that delays the feature processing and lowers the stopping distance of the system. In this work we propose a novel sensor fusion framework where a forward looking infrared (FLIR) camera is used as a prescreener, providing suspicious locations to the GPR-based system with zero latency. The FLIR camera is another detection modality that typically yields a higher FAR than GPR while offering much larger stopping distances. This makes it well-suited in the role of zero-latency prescreener. In this framework, GPR-based feature processing can begin without any latency, improving stopping distances. This framework was evaluated using well-known FLIR and GPR detection algorithms on a large

dataset collected at a Western US test site. Experiments were conducted to investigate the tradeoff between early stopping distance and FAR. The results indicate that earlier stopping distances are achievable while maintaining effective FARs. However, because an earlier stopping distance yields less data for feature extraction, there is a general tradeoff between detection performance and stopping distance.

9072-33, Session 8

Shallow depth subsurface imaging with microwave holography

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Subsurface sounding at shallow depths using microwaves is traditionally approached using pulsed ground penetrating radars. These radars record time of flight when two-dimensional signal is acquired over an area of interest. Post processing of acquired data results in a stack of images for further analysis. With such a technique, a detected anomaly can be classified based on object visible features, the quantity and quality of which depends on resolution of radar system. In the paper microwave holography is considered as a tool to obtain high resolution images of shallowly buried objects. The acquisition of signal is performed at a grid of frequencies by a two-dimensional mechanical scanner moving single transceiver over an area of interest at close proximity to the surface. The described FFT-based reconstruction technique is used to obtain a stack of plan view images considering only one selected frequency from operating frequency set. The extent of synthetically formed aperture and the wavelength define plan view resolution, which at sounding frequencies at 4 and 7 GHz amounted to 3 and 2 cm respectively. The system has remarkably short depth of focus which allows easy selection of proper focusing depth. Small distance of the buried objects to the antenna does not prevent from obtaining clean images due to multiple reflections of the signal as it happens with impulse radars. The description of the system hardware and signal processing technique is assisted by the description of experiments conducted in dry sand. The microwave images of anti-personnel and anti-tank mines and various clutter objects are demonstrated. Those images allow target discrimination based on the same optically observable small features. The demonstrated technology is seen promising to be modified and employed according to specific practical needs required in demining or survey systems. As an example of such modification to inspect construction materials, holographic subsurface radar RASCAN is considered.

9072-34, Session 8

Deep learning algorithms for detecting explosive hazards in ground-penetrating radar

Lance E. Besaw, Philip J. Stimac, Applied Research Associates, Inc. (United States); Brian P. Burns, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Improvised explosive devices (IEDs) and other buried explosive hazards (BEHs) have been, and continue to be, one of the most deadly threats on the modern battlefield. Current handheld sensors rely on a highly trained operator for them to be effective in detecting BEHs. New algorithms are needed to reduce the burden on the operator and improve the performance of handheld explosive hazard detectors. Traditional anomaly detection and discrimination algorithms use "hand-engineered" feature extraction techniques to characterize and classify threats. In this work we use state-of-the-art Deep Feature Learning (DFL) algorithms to transcend the traditional approaches of BEH detection (e.g., principal component analysis and real-time novelty detection techniques). Recently, DFL approaches have proven superior to traditional hand-engineered feature extraction methodologies of the past 20+ years because the algorithms automatically learn the important features from the data at multiple scales of abstraction without explicit human feature-engineering. DFL techniques use unsupervised learning to generate compressed representations of unlabeled, input data and supervised learning to generate input-output mapping of labeled training data. DFL approaches are well suited for BEH detection because they 1) are computationally efficient, 2) can compactly represent highly non-linear functions, and 3) have proven capable of accurate classification in noisy environments. We use DFL algorithms to process state-of-the-art ground penetrating radar data and detect BEHs.

9072-35, Session 8

Vehicle-mounted ground penetrating radar (Mine Stalker III) field evaluation in Angola

Stephen J. Laudato, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The U.S. Department of Defense Humanitarian Demining Research and Development (HD R&D) Program, The Non-Intrusive Inspection Technology (NIITEK), Inc. and The HALO Trust have over the last decade funded, developed and tested various incarnations of a prototype vehicle mounted ground penetrating radar (GPR) system dubbed the Mine Stalker. The HD R&D Program and NIITEK developed the Mine Stalker to detect low metal anti-tank (LM AT) mines in roads. The country of Angola is severely affected by LM-AT mines in roads, some of which are deeply buried. The threat from LM AT mines such as the South African Number 8 and the Chinese Type 72 still persist from Angola's 30 years of civil war. Many of these LM AT threats are undetectable at depths greater than 5 to 10 centimeters using metal detection technology. Clearing these routes is a critical requirement before Angola can rebuild its infrastructure and improve safety conditions for the local populace. The Halo Trust, a non-governmental demining organization (NGO) focused on demining and clearance of unexploded ordnance (UXO), has partnered with the HD R&D Program to conduct an operational field evaluation (OFE) of the Mine Stalker in Angola. Preliminary testing and training efforts yielded encouraging results. This paper presents a comprehensive review of the data collected, testing results, system limitations, and deficiencies while operating in a real world environment. Our goal is to promote discussion and recommendations for hardware and software improvements, while providing valuable data collected and documented under real world conditions for continued development of the system's automatic target recognition algorithms.

9072-36, Session 9

Towards eye-safe standoff Raman imaging systems

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Standoff Raman imaging systems have shown the ability to detect single explosives particles. However the laser intensities needed restricts the applications where they can be safely used. The next generation imaging Raman system has been developed based on a 355 nm UV laser, and in addition to eye-safety allowing discrete/invisible measurements. The non-dangerous exposure levels for the eye are several orders of magnitude higher in UVA than in the visible range.

FOI in collaboration with VTT have developed an imaging system capable of precise selection of Raman shifts in combination with high out-of-band blocking. The system is based on a by VTT developed compact, high resolution (0.2 nm @ FWHM) UV Fabry-Perot Interferometer (UV-FPI). The stable operation of the UV-FPI module under varying environmental conditions is arranged by controlling the temperature of the module and using a closed loop control of the FPI air gap based on capacitive measurement. Until now there has not existed a tunable wavelength filter in the UV-range with high enough performance to allow Raman imaging of minute traces.

The system presented consists of a 3rd harmonics Nd:YAG laser with 1.5

W average output at 1000 Hz, a 200 mm Schmidt-Cassegrain telescope, UV-FPI filter and an ICCD camera for signal gating and detection. The design principal leads to Raman spectrum in each image pixel. The system is designed for field use and easy maneuvering.

A plate with a pattern of holes in decreasing sizes has shown the ability to detect ammonium nitrate particles down to ~300 μm on 10 meter distance. Measurement time varies between 10-60 s depending on sensitivity and number of substances scanned for.

9072-37, Session 9

An excimer-based FAIMS detector for detection of ultra-low concentrations of explosives

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Currently, the development of the methods providing increase in sensitivity of gas analyzers for detecting of ultralow concentrations of organic compounds in air is a needed and urgent problem.

A new method of explosives detection based on the field asymmetric ion mobility spectrometry (FAIMS) and ionization by an excimer emitter has been developed jointly with portable detector. The excimer emitter differs from usual UV-ionizing lamps by mechanism of emitting, energy and spectral characteristics. The applied Ar2-excimer emitter has the working volume of 1 cm3, consuming power 0,6 W, the energy of photons of about 10 eV (?=126 nm), the FWHM radiation spectrum of 10 nm and emits more than 1016 photon per second that is two orders of magnitude higher than UV-lamp of the same working volume emits. This also exceeds by an order of magnitude the mean power of 10-Hz solid state Nd3+ - laser of 1mJ pulse energy at ?=266 nm that is also used to ionize the analyte. The Ar2-excimer ionizes explosives by direct ionization mechanism and through ionization of organic impurities. The developed Ar2-excimer-based ion source does not require cooling due to low level discharge current of emitter and could work with no repair more than 10000 hrs.

The developed detector can analyze both vapors and traces of explosives. The FAIMS spectra of the basic types of explosives like TNT, RDX, DNT, NG, ANFO, PETN, octogene etc. under Ar2-excimer ionization are presented. The detection limit determined for TNT vapors equals 1x10-14 g/cm3 , for TNT traces - 100 pg.

9072-38, Session 9

Filter-based chemical sensors for hazardous materials

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The development of new techniques for the detection of homemade explosive devices is an area of intense research for the defense community. Such sensors must exhibit high selectivity to detect explosives and/or explosives related materials in a complex environment. Spectroscopic techniques such as FTIR are capable of discriminating between the volatile components of explosives, however, there is a need for less expensive systems for wide-range use in the field. To tackle this challenge we are investigating the use of multiple, overlapping, broad band infrared (IR) filters to enable discrimination of volatile chemicals associated with an explosive device from potential background interferents with similar chemical signatures.

We present an optical approach for the detection of fuel oil (the volatile component in ammonium nitrate-fuel oil explosives) that relies on IR absorption spectroscopy in a laboratory environment. Our proposed system utilizes a three filter set to separate the IR signals from fuel oil and various background interferents in the sample headspace. Filter responses for the chemical spectra are calculated for various filter sets.

We demonstrate that using specific filter sets allows distinguishing between pure fuel oil, hexanes, and acetone, as well as various mixtures of these components. We examine the effects of varying carrier gasses and humidity on the collected spectra and corresponding filter response. We study the filter response on these mixtures over time as well as present a variety of methods for analyzing the filter response functions to determine the response of this approach to detecting fuel oil in various environments.

9072-39, Session 10

FRI for standoff detection of IED

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Applications of "forced-resonance-imaging" (FRI) for standoff detection of concealed IED (PBIED and VBIED) are presented with the aid of examples using live explosives. Research on the subject was initiated in 2008. It uses the radar principle to arrive at a novel technique for interrogation of personnel and vehicles (cargo, etc.) for explosives. This novel low power electromagnetic platform is capable for almost real time realization of PBIED and VBIED at standoff using either fixed portal configuration (transmission mode) or vehicle mounted configuration (reflection mode). Sensor development has been done based on the "Weak Signal" theory and utilizing a newly developed concept of "forced- resonance" in which the target (IED) frequency response is measured sequentially through a number of discrete frequency steps within the operating bandwidth of the detection algorithm. The overall system is configured to transmit low-power RF energy (between 6-dBm to 10-dBm equivalent to 3.99 mw to 10.02 mw) through 51 sequential steps within a pre-selected operating frequency band for personnel / vehicle borne explosive detection. The intermediate frequency (IF) for internal processing of the received signal is maintained at 1000 Hz. Combination of 51 frequency steps and 1000 Hz IF will provide the fastest possible sequential trace by trace interrogation of vehicle for a pre-selected operating frequency band. The amount of explosive would be from 1-kg to 400-kg and the time to scan an average size personnel / vehicle moving at a slow speed would be 3.1 seconds. Moving personnel / vehicles are fielded within the low-power transmitted regime of sensors and presence or absence of the explosive is detected by real time processing of received signal. Each radar trace is acquired at a rate of 0.069 second at a pre-established standoff distance. The received signal from personnel / vehicle under investigation is processed and should it contained explosive material a colored or white radar cross-section (signature) depending on the display mode, appears instantly on the monitoring screen to warn the operator of the inherent danger. The monitoring display screen can be installed near the sensor or remotely in another check point or multiple locations for real time observation. Once the presence of explosive is detected in a personnel / vehicle then the necessary decision can be made using the protocol to neutralize or cease its functionality through available assets. The design of an appropriate candidate sensor for IED detection must be based on accounting for the material make up in addition to the density and size of the explosive fill. This makes the BakhtarRadar uniquely qualified as a novel platform for such detection because its realization is primarily dependent on material makeup as demonstrated in a recent investigation conducted on "shielded weapons grade nuclear material" detection at Las Alamos National Laboratory (LANL). FRI provides a cost effective sensor for standoff detection of IED and can be configured for ease of installation either in portal or mobile configuration. Examples are provided on detection and discrimination of vehicle and personnel borne IEDs.

9072-40, Session 10

Low-cost detection of RC-IED activation signals in VHF band

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The proliferation of RC-IED is a growing threat around the world, the ease of construction and low cost of such devices are transforming common things in lethal tramps. The fight against this threats normally involve the use of sophisticated and expensive equipments of Electronic Warfare based on high speed DSP systems, just to detect the presence of detonation signals. In this work is showed how to find activation signals based on the characteristic of the power in a specific band and the previous knowledge about the detonation signals. As proof of concept we have taken the information about the RC-IEDs used in the Colombian conflict and develop an algorithm to find detonation signals based on the measured power in frequencies between 136MHz and 174MHz (Civil 2 meter band)

9072-41, Session 10

Prospect for standoff detection using a coherent high-harmonic x-ray beam

Henry C. Kapteyn, Margaret M. Murnane, Univ. of Colorado at Boulder (United States)

No Abstract Available

9072-42, Session 11

Ladar-based IED detection

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In the last decades improvised explosive devices, IED's, have become an everyday threat for armed forces accounting for many lost lives. An IED is a bomb constructed and deployed in a non-standard manor. They are used in many situations but the particular one that we are addressing is the roadside bomb. An object filled with explosive and connected to some sort of triggering mechanism or a cell phone is placed just beside the road and when a car drives by it is triggered. The scenario with road side IED's is a particular active research topic since it is feasible to detect that something has changed or seems out of place. A trained operator can sometimes see this type of IED before it is too late and it should be possible to construct an automatic system to do the same.

In this paper we present our research on Ladar-based IED detection where we perform change detection on laser scanned data. The idea is to acquire and store a model of the surroundings under normal conditions and be able to detect new, missing or changed objects. To gain knowledge on the lower boundaries of the needed resolution we have done static measurements with a high resolute terrestrial Riegl VZ-400 laser scanner. We present our findings from various measurements and conclude which objects may be detected and with which algorithms. Our goal however is a dynamic system and we have developed a relatively simple demonstrator based on a SICK LMS-511 scanner and a navigation system based on stereo vision combined with IMU and GPS. We present some preliminary results from this system.

9072-43, Session 11

Investigation of different localization strategies for spatial and spectral features for buried explosive hazard detection in FL-LWIR

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It is well-known that a pattern recognition system is only as good as the features it is built upon. In the fields of image processing and computer vision, we have numerous spatial domain and spatial-frequency domain features to help characterize aspects of imagery such as color, shape, and texture. However, these features suffer at times in part from the fact that they extract both object(s) of interest and background (surrounding context) information. A goal of this research is to filter as much task-specific irrelevant information as possible, e.g., tire tracks, surface texture, etc., to allow a system to focus on image features in spatial regions that likely belong to the object(s) of interest. Herein, this is coined soft feature extraction.

This idea is demonstrated in the context of an explosive hazards detection system using forward looking infrared imagery. We also investigate different ways to spatially contextualize and calculate statistical features from shearlet filtered candidate image chips. Furthermore, we investigate different localization strategies relative to exploitation of surrounding background context and different ways to group these image features to reduce the false alarm rate of an explosive hazard detection system. Performance is explored in the context of Receiver Operating Characteristic curves on data from a U.S. Army test site that contains multiple target and clutter types, burial depths, and times of day.

9072-44, Session 11

A method of evolving novel feature extraction algorithms for detecting buried objects in FLIR imagery using genetic programming

Alex Paino, James M. Keller, Mihail Popescu, Kevin E. Stone, Univ. of Missouri-Columbia (United States)

In this paper we present an approach that uses Genetic Programming (GP) to evolve novel feature extraction algorithms for greyscale images. Our motivation is to create an automated method of building new feature extraction algorithms for images that are competitive with commonly used human-engineered features, such as Local Binary Pattern (LBP) and Histogram of Oriented Gradients (HOG). The evolved feature extraction algorithms are functions defined over the image space, and each produce a real-value feature vector of variable length. Each evolved feature extractor breaks up the given image into a set of cells centered on every pixel, performs evolved operations on each cell, and then combines the results of those operations for every cell using an evolved operator. Using this method, the algorithm is flexible enough to reproduce both LBP and HOG features. The dataset we use to train and test our approach consists of a large number of pre-segmented image "chips" taken from a Forward Looking Infrared Imagery (FLIR) camera mounted on the hood of a moving vehicle. The goal is to classify each image chip as either containing or not containing a buried object. To this end, we define the fitness of a candidate solution as the cross-fold validation accuracy of the features generated by said candidate solution when used in conjunction with a Support Vector Machine (SVM) classifier. In order to validate our approach, we compare the classification accuracy of an SVM trained using our evolved features with the accuracy of an SVM trained using mainstream feature extraction algorithms, including LBP and HOG.

9072-45, Session 11

Convolutional neural network approach for buried target recognition in FL-LWIR imagery

Kevin E. Stone, James M. Keller, Univ. of Missouri-Columbia (United States)

A convolutional neural network (CNN) approach to recognition of buried explosive hazards in forward-looking long-wave infrared (FL-LWIR) imagery is presented. The convolutional filters in the first layer of the network are learned in the frequency domain, making enforcement of

zero-phase and zero-dc response characteristics much easier. The spatial domain representations of the filters are forced to have unit l2 norm, and penalty terms are added to the online gradient descent update to encourage orthonormality among the convolutional filters, as well smooth first and second order derivatives in the spatial domain. The impact of these modifications on the generalization performance of the CNN model is investigated. The CNN approach is compared to a second recognition algorithm utilizing shearlet and log-Gabor decomposition of the image coupled with cell-structured feature extraction and support vector machine classification. Results are presented for multiple FL-LWIR data sets recently collected from US Army test sites. These data sets include vehicle position information allowing accurate transformation between image and world coordinates and realistic evaluation of detection and false alarm rates.

9072-46, Session 11

Road recognition in poor quality environments for forward looking buried object detection

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Detecting unpaved roads in a poor quality environment is an important step toward autonomous navigation. In the application of forward looking buried object detection, it is crucial to anticipate directional changes so that the imaging systems can adapt apriori. Unlike road detection in paved streets or highways, unpaved roads in a desert environment introduce many complications to the road detection algorithm, such as similarity in color and texture on both road and non-road areas and the absence of clearly defined road edges. Also, unpaved roads may include many foreign objects like grass, rocks, road wash-outs, or even trees and bushes. The varieties of these foreign objects are too many to be included all in the training data.

In this paper, we propose a reinforcement random forest algorithm as a novel approach to detect unpaved road regions at stand-off distances. A random forest classifier is used to differentiate between road and non-road pixels/patches without over fitting the training data. Utilizing the reinforcement technique, the algorithm can handle foreign objects that we encounter in real world driving. Furthermore, classifying road pixels at different distances generate multiple levels of road confidence for each pixel. Using different threshold values of this confidence level provides adaptability to the road finding results. The selection of low threshold value produces better detection rates but also increases false alarms. On the other hand, high threshold values lower the detection rate and decreases false detections. The proposed algorithm is tested on color video of unpaved roads from an arid environment.

9072-47, Session 12

Detection of obscured and partially covered objects using partial network matching and an image feature network-based object recognition algorithm

Jeremy Straub, The Univ. of North Dakota (United States)

An approach to image classification based on the analysis of the network of points generated by an image feature detection algorithm has been proposed. This network-based approach is designed to look at the networks produced by two images of similar or dissimilar objects and scale and then compare them, making a classification decision. The scaling is based on using maximal or quartile (25%, 50%, 75%) node-to-node path lengths to characterize the relative size of the two input images. Using this approach, the resolution of the image or the distance from the target is abstracted (though it is still relevant from a visibility of image feature perspective). The distance between image features of various types is used to create a network of type-specific feature-to-feature distances. This network is compared to the networks of various known objects (or could be used to match unknown objects to other unknown objects). This network approach makes the method object-rotation agnostic. A partially covered or obscured object, however, is problematic as it impairs the scaling algorithm, making the subsequent matching less accurate and reducing the accuracy of the classification decision.

This paper considers several techniques to handle the similar problem posed by input images that are obscured or in which the target is partially covered. These approaches, which include scaling based on mean, median and mode values (instead of maximal / quartile values), are compared with the base algorithm to assess the impact on performance in the general case, obscured scenarios and obstructed scenarios. This assessment is performed both qualitatively and quantitatively.

9072-48, Session 12

3D LASE-M three-dimensional-lidar airborne system emulator maritime

Michael J. DeWeert, BAE Systems (United States)

Imaging flash LIDAR is an effective method for airborne searches of the ocean surface and subsurface volume. The performance of ocean LIDAR depends strongly on the sea surface (waves, whitecaps, and flotsam), on water turbidity, and on the characteristics of the objects of interest. Cost-effective design of the LIDAR system and processing algorithms requires a modeling capability that can deal with the physics of light propagation through the air-water interface, into the ocean, and back to the LIDAR receiver. 3DLASE-M is a physics-based LIDAR simulator that yields high-fidelity images for 3-dimensional algorithm development and performance predictions. Among the effects captured are:

* Laser glint and glitter
* Focusing and de-focusing due to surface wave refraction
* De-polarization of propagating laser light
* Multiple-scattering-induced beam spread and image blurring
* Absorption and backscatter in the water volume
* Variable target and bottom reflectance

The simulator uses a hybrid engine that combines ray tracing with small-scattering theory to run much faster than purely Monte-Carlo models. It also incorporates a quasi-universal scattering phase function, making it applicable to a wide range of water types. The sea surface is modeled with the US Army Corps of Engineers TMA model, with a selectable directional spectrum.

9072-49, Session 12

Detection of obscured targets with IR polarimetric imaging

David B. Chenault, Joseph L. Pezzaniti, Polaris Sensor Technologies, Inc. (United States)

A polarization thermal sensor is presented that has ability to detect manmade objects even when there is little or no thermal contrast, or when the object is obscured by clutter or vegetation. Imagery will be shown for scenarios in which polarization contrast remains high during periods of zero thermal contrast. Also, data will be presented that shows the detection of manmade targets in natural clutter, long after thermal equilibrium of the target with the background has been established.

9072-50, Session 12

Investigation of disturbed earth detection in the very long wavelength infrared (VLWIR)

Kenneth J. Ewing, Jas S. Sanghera, U.S. Naval Research Lab. (United States)

The Reststrahlen effect, which refers to an enhanced reflectance for soils in the 7 – 9 μm wavelength range, can be used to detect disturbed earth associated with buried IEDs. The Reststrahlen band intensity is proportional to the size and distribution of silica particles in surface and sub-surface soil. Soils containing predominantly large silica particles exhibit a greater intensity Reststrahlen band than soils containing a greater fraction of smaller silica particles. Undisturbed surface soil contains primarily large silica particles while smaller silica particles are present in the subsurface soil. This distribution is primarily driven by weathering of the soil by wind and rain over time. When the earth is disturbed by digging the size distribution of silica particles is changed resulting in the disturbed earth surface soil containing a greater number of small silica particles then the surrounding surface soil. This results in a decrease in the reflected light for the disturbed earth which can be detected as a difference in contrast in an IR image of disturbed and undisturbed earth enabling identification/location of buried IEDs.

This paper investigates the utility of a second Reststrahlen band in the 17 – 25 μm spectral region for the enhanced detection of disturbed earth.

9073-1, Session 1

Active FTIR-based standoff detection in the 3-4-micron region using broadband femtosecond optical parametric oscillators *(Invited Paper)*

Derryck T. Reid, Zhaowei Zhang, Heriot-Watt Univ. (United Kingdom); Christopher R. Howle, Defence Science and Technology Lab. (United Kingdom)

We describe the implementation of standoff Fourier transform infrared (FTIR) spectroscopy using a broadband mid-infrared optical parametric oscillator (OPO). This signal-resonant OPO was based on a 20 mm-long magnesium oxide doped periodically poled lithium niobate (PPLN) crystal and synchronously pumped by a fiber amplifier seeded by a mode-locked Yb: KYW laser. The mid-IR idler output from the OPO had an average power of 100 mW, with a spectral coverage over 2700 -3200 cm-1. The pulse width and pulse repetition rate of the mid-IR pulse train were ~3 ps and 100 MHz respectively.

The mid-IR OPO output was collimated to a diameter of approximately 8 mm, then directed to a home-built FTIR spectrometer consisting of a Michelson interferometer with a scanning mirror. Along with the mid-IR OPO beam, a 632.8-nm He-Ne beam was coupled into the interferometer for absolute frequency calibration of spectroscopic signals. After the interferometer, the light was directed to the surface of interest and the scattered light collected by an MCT or PbSe detector. No averaging was required, and only point sampling was implemented, with an acquisition rate of ~10 Hz, which could be significantly improved by use of a faster scanning mirror for the Michelson interferometer.

Remote detection for water vapor, chemical agent resistant coating (CARC), and a thiodiglycol droplet, on highly-irregular real-world surfaces, including a concrete, a CARC plate and an aluminium plate, was demonstrated at a standoff distance of 2 meters with excellent signal to noise.

Compared with an 'incoherent' high-temperature blackbody radiation source, a broadband mid-infrared optical parametric oscillator source is inherently more suitable for standoff spectroscopy because of its excellent spatial coherence and high spectral brightness.

This technique promises to open up many applications including environmental diagnosis, detection of gas leaks or toxic industrial spills, identification of chemical warfare agents, explosives or other hazardous materials, and analysis of contaminated water or soils.

9073-2, Session 1

Quantitative total and diffuse reflectance laboratory measurements for remote and standoff sensing

Thomas A. Blake, Carolyn S. Brauer, Yin-Fong Su, Bruce E. Bernacki, Tanya L. Myers, Brenda M. Kunkel, Timothy J. Johnson, Pacific Northwest National Lab. (United States)

Past laboratory and field work by researchers performing thermal infrared remote sensing of geological surfaces, for example, has shown that for most materials a laboratory measurement of the total directional/hemispherical reflectance, R, of a target surface and the use of Kirchhoff's law gives a good approximation to the emissivity, e, of that surface: e = 1 – RT. Using a Fourier transform spectrometer (FTS) and a commercial-off-the-shelf integrating sphere with a matte gold coating we have begun to construct a quantitative database of total and diffuse reflectance spectra covering the wavelength range 1.3 to 16.7 microns for materials relevant to remote and standoff sensing for security scenarios. Protocols for measuring total and diffuse reflectance of surfaces using the FTS and sphere are provided and estimates for systematic and random error in the measurements are given. Results for measurements of reflectance standard materials as well as data from several materials of interest will also be presented. A complementary reflectance database for the same materials is also being developed in the visible and near infrared (VNIR). The VNIR data, which is measured using a dispersive spectrometer and Spectralon coated sphere, overlaps with the infrared data in the shortwave region. Reflectance data comparisons from the two instruments in the overlap region will also be given.

9073-3, Session 1

Development of an ultrahigh-performance infrared detector platform for advanced spectroscopic sensing systems

Manish Jain, Amethyst Research Inc. (United Kingdom); Gary W. Wicks, Amethyst Research Inc. (United States) and Univ. of Rochester (United States); Andrew R. J. Marshall, Adam Craig, Lancaster Univ. (United Kingdom); Terry Golding, Amethyst Research Inc. (United States) and Amethyst Research Ltd. (United Kingdom); Khalid Hossain, Amethyst Research Inc. (United States); Christopher R. Howle, Kenneth J. McEwan, Defence Science and Technology Lab. (United Kingdom)

Implementation of laser-based remote (standoff) sensing of threat agents (explosives, toxic industrial chemicals or chemical warfare agents), by detecting the distinct infrared spectral absorption signature of these materials, has made significant advances recently. This is due in part to the availability of infrared and terahertz laser sources with significantly improved power and tunability. However, there is a pressing need for a versatile, high performance multispectral infrared sensor that can complement and enhance the recent advances achieved in laser technology. In this paper we discuss and present results of new, high performance infrared detectors based on III-V barrier diodes. Unipolar barrier diodes, such as the nBn, have been very successful in the MWIR using InAs(Sb)-based materials, and in the LWIR using type-II InAsSb/InAs superlattice-based materials. This work addresses the extension of the barrier diode architecture into the SWIR region, using GaSb-based and InAs-based materials. The program has resulted in detectors with unmatched performance in the 2-3 micron spectral range. Temperature dependent characterization has shown dark currents to be diffusion limited and equal to, or within a factor of 5, of the Rule 07 expression for Auger-limited HgCdTe detectors. Furthermore D* values are superior to those of existing detectors in the 2-3 micron band. Of particular significance to spectroscopic sensing systems is the ability to have near-BLIP performance at operation temperatures compatible with robust and reliable solid state thermoelectric coolers.

9073-4, Session 1

Real-time identification of aerosol sized particles using single-beam CARS

Stephen D. Roberson, EOIR Technologies (United States); Paul M. Pellegrino, U.S. Army Research Lab. (United States)

There is a need for rapid and accurate detection and identification of complex aerosol particles in a number of fields for countless applications including an on-the-fly bio-aerosol hazard warning system pursued by the chemical and biological defense community. Prior works has explored numerous methodologies to classifiy or identify possible aerosol hazards using elastic scattering, polarimetric elastic scattering and fluorescence with limited success at full identification. Full identification has been hampered by the inability to use information-rich spectroscopic methods such as Raman scattering in a flowing aerosol environment. Recently, multiplex coherent anti-Stokes Raman spectroscopy (MCARS) has been shown to generate a complete Raman spectrum from the material of interest that can be detected in milliseconds, effectively allowing for real time Raman detection. MCARS creates this vast improvement on signal strength by using a single ultrabroadband pulse to coherently drive multiple molecular vibrations simultaneously, creating a complete Raman spectrum from single laser pulse. The use of MCARS to create a real time Raman spectrum would be a significant step forward in the continuing effort to assess aerosol-sized threats in real time without sacrificing the much-needed molecular information. The effort to perform in situ real time detection of a single droplet of an aerosol-sized material of interest (e.g., nerve agent simulant, explosive precursors) using MCARS will be reported. Additionally, the effect of varying aerosol droplet diameter on the efficacy of detection and identification will also be discussed.

9073-5, Session 1

The application of adhesive coatings for trace sampling, chemical detection, and forensics

Jessica Staymates, National Institute of Standards and Technology (United States)

Several uses of a high-temperature resistant silicone adhesive material for trace chemical sampling and detection are presented. In many trace sampling applications, surface wipe sampling is the primary method used to collect contraband contamination from a surface or object. The ability of the wipe material to effectively collect this contamination has been the focus of many studies in the past, and results suggest that improvements in collection efficiency are needed [1,2]. In this work, a unique adhesive material is applied directly to the surface of a wipe collection material and allowed to cure, resulting in a wipe that has a factor of ten improvement in particle collection efficiencies compared to regular wipe materials. Chemical analysis via ion mobility spectrometry (IMS), particle collection efficiency experiments via fluorescent microscopy, and high-speed videography of particle collection were used to confirm the results. This presentation will describe the results of many experiments conducted to fully examine the usefulness of these adhesive swabs. Results, feasibility, and potential issues with using this method will be discussed, and videos and images used for characterization of the method will be presented.

Also, a new methodology using this concept of adhesive coatings has been developed and evaluated for biometric-related applications, specifically lifting latent fingerprints, and combined with trace chemical analysis. A collection swab coated with a high-temperature adhesive is used to collect a developed latent fingerprint from a surface, and the swab is directly inserted into an IMS for quick and immediate chemical analysis. After the IMS analysis, the lifted print remains intact for subsequent biometric scanning and matching algorithms. The ability to collect a latent print and heat it for chemical analysis while keeping the print intact may be useful for law enforcement and military operations, and could potentially reduce the cost and delay of sending fingerprint samples to a lab for chemical analysis. Topics such as sample preparation and collection and usefulness of the lifted fingerprints will be presented.

[1] Verkouteren, et al., Meas. Sci Technol. 2008 19 115101.

[2] Staymates et al., Anal.Methods 2011 3(9) 2056-2060.

9073-6, Session 1

Photoacoustic chemical sensing: ultracompact sources and standoff detection

Logan S. Marcus, Ellen L. Holthoff, John F. Schill, Paul M. Pellegrino, U.S. Army Research Lab. (United States)

Photoacoustic spectroscopy (PAS) is a useful monitoring technique that is well suited for trace detection of gaseous and condensed media. We have previously demonstrated favorable PAS gas detection characteristics when the system dimensions are scaled to a micro-system design. This design includes quantum cascade laser (QCL)-based microelectromechanical systems (MEMS)-scale photoacoustic sensors that provide detection limits at parts-per-billion (ppb) levels for chemical targets. Current gas sensing research utilizes an ultra compact QCL, SpriteIR, in combination with a MEMS-scale photoacoustic cell for trace gas detection. At approximately one tenth the size of a standard commercially available QCL, SpriteIR is an essential element in the development of an integrated sensor package. We will discuss these results as well as the envisioned sensor prototype. Finally, expanding on our previously reported photoacoustic detection of condensed phase samples, we are investigating standoff photoacoustic chemical detection of these materials and will discuss preliminary results.

9073-7, Session 1

Multispectral imaging of CBRNE threats using micro-optics

Michele Hinnrichs, Pacific Advanced Technology, Inc. (United States); James O. Jensen, U.S. Army Edgewood Chemical Biological Ctr. (United States)

This paper is a follow-on paper to one presented at SPIE in 2012 describing a design for a snapshot multi-spectral camera that can be used for CBRNE applications. An update on the development effort and preliminary testing will be given. Under support by the US Army SBIR program a multi-spectral SWIR/MWIR snapshot camera was developed. The snapshot camera uses a 1280 x 1024, 12 micron pixel pitch InSb focal plane array (FPA) which is divided into 16 spectral images consisting of 256 x 256 pixels each. Each of the sixteen different spectral images has a bandpass of 0.04 microns. The micro-optic array (lenslet array) is fabricated on ZnSe with each lenslet measuring 3 mm in diameter and a nominal focal length of 7 mm or f/2.33.

To expand the 16 multi-spectral snapshot images to a hyperspectral camera the lenslet array is translated along the optical axis with piezoelectric actuation in synchronization with the camera frame rate to perform band fill-in. By multiplexing 16 simultaneous spectral images an entire hyperspectral data cube can be collected rapidly. The simultaneous detection of multiple spectral images in a single frame also enhances the image processing capability by eliminating temporal differences between colors and reduces motion sensitivity.

9073-8, Session 2

A neural network structure for prediction of chemical agent fate

Homayun K. Navaz, Kettering Univ. (United States); Nasser Kehtarnavaz, University of Texas at Dallas (United States); Zoran Jovic, Kettering University (United States)

This work presents the development of a multi-input, multi-output neural network structure to predict the time dependent concentration of chemical agents as they participate in chemical reaction with environmental substrates or moisture content within these substrates. The neural network prediction is based on a computationally or experimentally produced database that includes the concentration of all chemicals presents (reactants and products) as a function of the chemical agent droplet size, wind speed, temperature, and turbulence. The utilization of this prediction structure is made user-friendly via an easy-to-use graphical user interface. Furthermore, upon the knowledge of the time-varying environmental parameters (wind speed and temperature that are usually recorded and available), the time varying concentration of all chemicals can be predicted almost instantaneously by recalling the previously trained network. The network prediction was compared with actual open air test data and the results were found to match.

9073-9, Session 2

Fate of sessile chemical agent droplet on porous environmental substrates in the presence of physiochemical processes

Homayun K. Navaz, Anthony Dang, Theresa Atkinson, Ali Zand, Albert Nowakowski, Kristina Kamensky, Kettering Univ. (United States)

The time dependent multi-phase and multi-component mass and momentum equations in a capillary domain are solved to address the environmental spread and fate of chemical agents, or in general, any chemical, upon their participation in simultaneous physiochemical processes. These processes include, transport through capillary substrates, evaporation, chemical reaction, and adsorption. The model is based on finite difference with Runge-Kutta fourth order integration in time. An extensive validation of the model with laboratory and open air data is performed to demonstrate the robustness and accuracy of the model.

9073-10, Session 2

Modeling the long-wave infrared reflectance signatures from contaminated surfaces

Travis R. Myers, Anish Goyal, William Herzog, Matthew Aernecke, MIT Lincoln Lab. (United States)

Active long-wave-infrared (LWIR) hyperspectral imaging is a promising technique for the standoff detection and mapping of chemicals on surfaces. However, the success of this technique depends on our ability to predict the shape of the reflectance spectra of the target chemicals in various environments. In this work, we present models for the reflectance spectra of liquids and solid particles on surfaces. We investigate the reflectance of diethyl phthalate (DEP) on diffuse gold and concrete surfaces and describe the observed changes in the reflectance spectra as a function of time and volume of DEP using a model that accounts for both the specular and diffuse components of the reflectance. We also investigate the reflectance of solid particles composed of sodium chlorate, potassium chlorate, and alumina on a variety of surfaces including gold, silica, and painted car panels. We use models and concepts derived from Mie Theory to explain how the shape of the reflectance spectra changes at various viewing geometries and with various particle size distributions. For our experiments, we used wavelength-tunable quantum cascade lasers with wavelengths that span 9.1 to 10.8 microns to illuminate the samples. The reflected radiation was collected by a HgCdTe focal-plane array (FPA) and the resulting hyperspectral image was analyzed at each wavelength to produce the reflectance spectra.

9073-11, Session 2

Measurements of Raman scattering in the middle ultraviolet band from persistent chemical warfare agents

Fredrik Kullander, Lars Landström, Hampus Lundén, Abdesalam Mohammed, Göran Olofsson, Pär Wästerby, Swedish Defence Research Agency (Sweden)

A low Raman scattering cross section often in combination with a strong fluorescence background limits the measuring range of Raman based instruments operating in the visible or infrared band. We are exploring if laser excitation in the middle ultraviolet (UV) band between 200 and 300 nm is advantageous for detection of persistent chemical warfare agents (CWA) using a tunable pulsed laser. UV Raman scattering from tabun (GA), mustard gas (HD), VX and relevant simulants in the form of liquid surface contaminations has been measured using a laboratory experimental setup with a short standoff distance around 1 meter.

The overall energy of the detected Raman signal from pure droplets of these substances is generally found to reach a peak within this laser excitation band. The Raman signal increase with decreasing laser excitation wavelength until the absorption band of the substances is reached and the signal strength starts to fall. The optimum excitation wavelength differs between the chemicals studied and is found to be dependent on the amount of substance being irradiated by the laser. A clear indication of resonance enhancement was not observed for any of the main peaks in the detected Raman spectra, possibly due to insufficient detector performance. The inherent fluorescence from these substances is gradually shifted out from the Raman detection band with decreasing laser excitation wavelength and is generally getting negligible around 250 nm. The results will be analysed to establish system requirements and detection limits. The experimental setup can also be used in material science of CB protection garments in the future. Our next major development will be to remodel the setup to an imaging system, to enable faster detection of contaminations.

9073-12, Session 2

Application of a Fourier-transform infrared imaging system to deciphering obliterated writings for forensic purposes

Shigeru Sugawara, National Research Institute of Police Science (Japan)

The decipherment of obliterated writing is important in forensic science. Generally, obliterated writings are deciphered using a spectroscopic image of visible and near-infrared light of 0.4–1 μm wavelength. However, there are certain obliterated writings that cannot be detected using conventional methods. The possibility of deciphering writings depends on the optical characteristic of the ink used to write the characters and that of the ink used to obliterate the writing. A method for deciphering such obliterated writings was developed in this study. Middle infrared light with a wavelength of 2.5–14 μm was used in an attempt to decipher obliterated writings; that is, a Fourier-transform infrared imaging system (Spectrum Spotlight 300, Perkin Elmer Co.) was used the first time for deciphering obliterated writings. The sample of obliterated writings was created by stamping concealing ink on a character written using black water dye ballpoint pens. The size of the sample was 5 mm x 5 mm. It was confirmed that the sample could not be detected using conventional methods. One pixel of the infrared image was 25 μm x 25 μm, and the wavenumber resolution was 16cm-1; One pixel of the infrared image was 25 μm x 25 μm.The concealed characters were revealed when the image was created from the peak area of the absorption peak at 1594 cm-1.

Obliterated writings that could not be deciphered with the conventional method could be deciphered using an image of infrared light with a wavelength of “2.5–14 μm”. Therefore, the infrared imaging system is useful for deciphering obliterated writings. The novel method can decipher concealed characters written using black materials with absorption peaks at 1594 cm-1. The number of such materials was 12 out of the 73 of my available black-writing materials. Moreover, the concealing ink must not have a peak at 1594 cm-1. All my 14 concealing inks satisfied this condition.

9073-13, Session 2

Xerogel-based molecularly imprinted polymers for biorecognition and chemical sensing

Ellen L. Holthoff, U.S. Army Research Lab. (United States); Kimberly L. Turner, Lily Li, Univ. of California, Santa Barbara (United States)

Molecularly imprinted polymers (MIPs) can be utilized as artificial recognition elements for target chemical and biological 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 non-covalent interactions between the functional monomer and the analyte. The objective of the present work is to demonstrate the usefulness of MIPs for chemical recognition and as substitutes for biorecognition elements. 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 results will demonstrate the effectiveness of MIPs for a variety of sensing applications, including fluorescence and microcantilever mass sensors.

9073-15, Session 2

Acoustic resonance in MEMS scale cylindrical tubes with side branches

John F. Schill, Ellen L. Holthoff, Paul M. Pellegrino, Logan S. Marcus, U.S. Army Research Lab. (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 microelectromechanical system (MEMS) design. One of the central issues related to sensor miniaturization is optimization of the photoacoustic cell geometry, especially in relationship to high acoustical amplification and reduced system noise. Previous work relied on a multiphysics approach to analyze the resonance structures of the MEMS scale photo acoustic cell. This technique was unable to provide an accurate model of the acoustic structure. In this paper we describe a method that relies on techniques developed from musical instrument theory and electronic transmission line matrix methods to describe cylindrical acoustic resonant cells with side branches of various configurations. An acoustic wave traveling in a duct can be modeled using electrical transmission line theory. Branches off the duct appear as impedances along the line. Much work has been done to describe tone holes in various wind instruments that can be directly applied to our MEMS scales photoacoustic cells. In this paper we develop a method to determine the resonance frequency of photacoustic cells with side branches of several different configurations that might be encountered when developing a cell. Testing was done with three different cells in different configurations, and the results matched those predicted by the theory within 2% in the worst case.

9073-16, Session 3

Proximal detection of energetic materials on fabrics by UV-Raman spectroscopy

Roberto Chirico, Salvatore Almaviva, Francesco Colao, Luca Fiorani, Marcello Nuvoli, ENEA (Italy); Wenka Schweikert, Frank Schnuerer, Fraunhofer ICT (Germany); Luigi Cassioli, Silvana Grossi, Leonardo Mariani, Aeronautica Militare (Italy); Federico Angelini, Ivano Menicucci, Antonio Palucci, ENEA (Italy)

A prototype of a new instrumentation (RADEX, RAman Detection of EXplosives) was developed at the Diagnostics and Metrology Laboratory (ENEA, Frascati) in the frame of the special NATO Science for Peace project STANDEX (STANd-off Detection of Explosives). The STANDEX program was defined to develop a stand-off explosive warning system, including fusion of explosives detection sensors, designed to work in mass transit infrastructures for homeland security applications. The RADEX project aimed at developing a new UV Raman-based apparatus in the field of the remote detection of energetic materials. The expected scenario was the monitoring of dispersed explosive compounds on the surface of clothes of people. The RADEX system was built to detect residues of explosives taking in consideration of the constraint of a maximum permissible laser exposure at the human cornea.

Raman-based spectroscopy has recently gained consents as potential tool for the detection of explosives due to technical improvements [1]. Ultraviolet (UV) excitation brings to improvements in the detection of the Raman signal because a lower interference from luminescence is experienced and the scattering cross section of substances increases [2].

RADEX is able to detect trace amounts of energetic materials on fabrics at a distance of 6-7 meters using a single pulse of an eye-safe UV laser.

References

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9073-18, Session 3

Stand-off imaging Raman spectroscopy for forensic analysis of post-blast scenes: trace detection of ammonium nitrate and 2,4,6-trinitrotoluene

Ema Ceco, Hans Oennerud, Dennis Menning, FOI (Sweden); John L. Gilljam, Stockholm Univ. (Sweden); Henric Östmark, FOI (Sweden)

The following proceeding presents a realistic forensic capability test of an imaging Raman spectroscopy based demonstrator system, developed at FOI, the Swedish Defence Research Institute. The system uses a 532 nm laser to irradiate a surface of 25x25mm. The backscattered radiation from the surface is collected by an 8" telescope with subsequent optical system, and is finally imaged onto an ICCD camera. We present here an explosives trace analysis study of samples collected from a realistic scenario after a detonation. A left-behind 5 kg IED, based on ammonium nitrate with a TNT (2,4,6-trinitrotoluene) booster, was detonated in a plastic garbage bin. Aluminum sample plates were mounted vertically on a holder approximately 6 m from the point of detonation. Minutes after the detonation, the samples were analyzed with stand-off imaging Raman spectroscopy from a distance of 10 m. Trace amounts of both the secondary explosive (ammonium nitrate) and the booster (TNT) were detected. The analysis time was 1 min. The sample plates were subsequently swabbed and analyzed with HPLC and GC-MS to confirm the results from the stand-off imaging Raman system. The presented findings indicate that it is possible to determine the type of explosive used in an IED from a distance, within minutes after the attack, and without tampering with physical evidence at the crime scene.

9073-19, Session 3

High-sensitivity explosives detection using dual-excitation-wavelength resonance-Raman detector

Balakishore Yellampalle, William B. McCormick, Hai-Shan Wu, Mikhail Sluch, Robert B. Martin, Robert V. Ice, Brian E. Lemoff, West Virginia High Technology Consortium Foundation (United States)

A key challenge for standoff explosive sensors is to distinguish explosives, with high confidence, from a myriad of unknown background materials that may have interfering spectral peaks. To meet this challenge a sensor needs to exhibit high specificity and high sensitivity in detection at low signal-to-noise ratio levels. We had proposed a Dual-Excitation-Wavelength Resonance-Raman Detector (DEWRRED) to address this need. In our previous work, we discussed various components designed at WVHTCF for a DEWRRED sensor. In this work, we show a completely assembled laboratory prototype of a DEWRRED sensor and utilize it to detect explosives from several standoff distances. The sensor system includes two novel, compact CW DUV lasers, a compact dual-band high throughput DUV spectrometer, and a highly-sensitive detection algorithm. We choose DUV excitation because Raman intensities from explosive traces are enhanced and fluorescence and solar background are not present. The DEWRRED technique exploits the excitation wavelength dependence of Raman signal strength, arising from complex interplay of resonant enhancement, self-

absorption and laser penetration depth. We show measurements from >10 explosives/pre-cursor materials at different standoff distances. The sensor showed high sensitivity in explosive detection even when the signal-to-noise ratio was close to one (~1.6). We measured receiver-operating-characteristics, which show a clear benefit in using the dual excitation wavelength technique as compared to a single-excitation-wavelength technique. Our measurements also show improved specificity using the amplitude variation information in the dual-excitation spectra.

9073-20, Session 3

Improved sensing using simultaneous deep-UV Raman and fluorescence detection-II

William F. Hug, Photon Systems, Inc. (United States); Rohit Bhartia, Jet Propulsion Lab. (United States); Kripa Sijapati, Ray D. Reid, Photon Systems, Inc. (United States)

This paper addresses the need to increase sensitivity and specificity for hand-held real-time sensors for trace levels of biological, chemical, and explosives materials. The method discussed uses simultaneous detection of Raman and fluorescence emissions excited in the deep UV between.

There are four main advantages of excitation in the deep UV compared to near-UV, visible or near-IR counterparts. 1) Excited in the deep UV below 250 nm, Raman emission occur within a fluorescence-free region of the spectrum, eliminating obscuration of weak Raman signals by fluorescence from target or surrounding materials. 2) Because Raman and fluorescence occupy separate spectral regions, detection can be done simultaneously, providing a much wider set of information about a target. 3) Rayleigh law and resonance effects increase Raman signal strength and sensitivity of detection. 4) Penetration depth into target in the deep UV is short, providing separation of a target material from it background or substrate.

The evolving sensor method can discriminate CBE from background materials using a combination of deep UV excited Raman and fluorescence emissions. Raman spectroscopy is a method that provides information about molecular bonds, while fluorescence spectroscopy is a much more sensitive method that provides information regarding the electronic configuration of target molecules. Photon Systems, in collaboration with JPL, has been developing combined Raman and fluorescence methods for over 12 years, focused on the advantages of excitation in the deep UV below 250nm.

9073-21, Session 3

Spatially offset hyperspectral stand-off Raman imaging for explosive detection inside containers

Bernhard Zachhuber, Henric Östmark, Swedish Defence Research Agency (Sweden)

A stand-off Raman imaging system for the identification of explosives was modified to allow for the analysis of substances in containers which are non-transparent to the human eye. The adaptation of this detection system extends its field of application from trace detection of threat materials on various background surfaces to the investigation of suspicious container content. Despite its limitation to container material that is opaque to the facilitated 532 nm laser, the combination of Spatial Offset Raman Spectroscopy (SORS) with stand-off Raman imaging allows to collect spectral data from a broad range of different spatial offsets simultaneously. This is a significant advantage over SORS with predefined offset, since the ideal offset is unknown prior to the measurement and depends on the container material as well as the sample content. Here the detection of sodium chlorate in a white plastic bottle is shown.

A 532 nm laser (pulse length 5 ns, repetition rate 50 kHz) was focused to a spot diameter of 10 mm on the sample surface at 10 m. A 1500 mm Schmidt-Cassegrain telescope with a diameter of 152.4 mm collected the scattered light. After the telescope an edge filter removed the inelastically scattered laser light and a liquid crystal tunable filter was used to select 0.25 nm broad wavelength ranges between 480 and 720 nm. The light from a sample area of 50x50 mm was imaged on the 1024x1024 pixels of an ICCD camera. For the conducted experiments an ICCD gate time of 5 ns was selected and 70 μJ-laser pulses, were accumulated during 1 s for each wavelength.

9073-22, Session 3

Improving sensitivity and source attribution of homemade explosives with low-frequency/THz-Raman

James T. A. Carriere, Frank Havermeyer, Randy A. Heyler, Ondax, Inc. (United States)

Rapid identification and source attribution of homemade explosives (HMEs) is vital to national defense and homeland security efforts. Since HMEs can be prepared in a variety of methods with different component ingredients, telltale traces can be left behind in the final structural form of the material. These differences manifest as polymorphs, isomers, conformers or even contaminants that can all impact the low energy vibrational modes of the molecule. Conventional Raman spectroscopy systems confine their measurements to the “chemical fingerprint” region and are unable to detect low frequency Raman signals (<200cm-1) where these low energy modes are found. This gap in sensitivity limits the conclusions that can be drawn from a single Raman measurement and creates the need for multiple measurement techniques to confirm any results.

We present results from a new rugged, portable approach that is capable of extending the range of Raman to include these low frequency signals down to ~5cm-1, with measurement times on the order of seconds. We demonstrate the diversity of signals that lie in this region that directly correlate to the molecular structure of the material, resulting in a new Raman “structural fingerprint” region. By correlating the measured results with known samples from a spectral library, rapid identification of the specific method of manufacture can be made.

Armed with this additional information about the methods and materials used to manufacture HMEs, officials can use this approach to rapidly respond to threats.

9073-23, Session 4

Hyperspectral imaging using novel LWIR OPO for hazardous material detection and identification

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Current stand-off hyperspectral imaging detection solutions that operate in the mid wave infrared (MWIR), nominally 2.5 – 5 μm region, are limited by the number of absorption bands that can be addressed. This issue is most apparent when evaluating a scene with multiple absorbers with overlapping spectral features making accurate identification challenging. This limitation can be overcome by moving to the long wave IR (LWIR) region, which is spectral rich in unique absorption features, which can provide ample molecular information in order to perform material identification with a high degree of confidence. This work utilises an instrument platform to perform negative contrast imaging using a novel LWIR optical parametric oscillator (OPO) as the source. The OPO offers continuous tuning in the region 5.5 – 9.5 μm, which includes a number of molecular vibrations associated with the target material compositions. Scanning the scene of interest whilst sweeping the wavelength of the OPO emission, will highlight the presence of a suspect material and by analysing the resulting absorption spectrum identification will be possible. This work presents a selection of initial results using the LWIR hyperspectral imaging platform on a range of hazardous, confusion and simulant materials to highlight the benefit operating in the LWIR region compared to the MWIR.

9073-24, Session 4

The challenge of changing signatures in infrared stand-off detection of trace explosives

Robert Furstenberg, Christopher A. Kendziora, Michael R. Papantonakis, Viet Nguyen, R. Andrew McGill, U.S. Naval Research Lab. (United States)

Analytical chemists have long known that careful sample preparation is needed to obtain consistent or reliable FTIR spectra. Grinding the sample to a fine (sub-micron) powder along with a KBr matrix and pressing a pellet is the prescribed technique. However, in stand-off detection, IR spectra need to be collected in-situ, without any sample preparation. In addition, the dominant fraction of explosives particle sizes found in latent fingerprints is typically in the range of 5-20 μm, which is within one order of magnitude of the IR wavelengths in the molecular "fingerprint" region. As a result, the analyte particle size and general morphology of the particle and substrate play an important role in shaping its IR signature. We report our preliminary results on numerical modeling and empirical measurements of IR back-scattering (reflectivity) and absorption (photo-thermal) IR signatures of micron-size, irregularly shaped particulates. We start with simple models that use the equivalent sphere approximation, such as the Mie theory of light scattering and continue with techniques that capture both the size and shape of the particles. The modeling results will be compared to empirically measured IR signatures of individual particles using our custom-built photo-thermal microscope. The effect of substrate optical properties on the overall IR signature will be studied as well. We discuss the conditions under which IR spectral signatures deviate the most from bulk values and also when this effect is less pronounced.

9073-25, Session 4

STARR: shortwave-infrared targeted agile Raman robot for the identification and confirmation of emplaced explosives

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In order to combat the threat of emplaced explosives (land mines, etc.), ChemImage Sensor Systems (CISS) has developed a fusion based, robot mounted sensor capable of identification and confirmation of potential threats. The system, known as STARR (Shortwave-infrared Targeted Agile Raman Robot), utilizes shortwave infrared spectroscopy for the identification of potential threats, combined with a visible short-range standoff Raman hyperspectral imaging (HSI) system for material confirmation. The entire system is mounted onto a Talon UGV (Unmanned Ground Vehicle), giving the sensor an increased area search rate and reducing the risk of injury to the operator. The Raman HSI system utilizes a fiber array spectral translator (FAST) for the acquisition of high quality Raman chemical images, allowing for increased sensitivity and improved specificity. This paper will present an overview of the design and operation of the system and discuss initial detection results.

9073-26, Session 4

Continued development of a portable widefield hyperspectral imaging (HSI) sensor for standoff detection of explosive, chemical, and narcotic residues

Oksana Klueva, Matthew P. Nelson, Charles W. Gardner, Patrick J. Treado, ChemImage Corp. (United States)

The value of Hyper Spectral Imaging (HSI) passive chemical detection employing widefield, standoff imaging continues to gain acceptance in defense and security fields. A portable platform that is robust and user-friendly increases the effectiveness of locating and identifying threats while reducing risks to personnel.

In 2013 ChemImage Sensor Systems (CISS) introduced Aperio™, a handheld sensor using real time HSI for wide area surveillance and standoff detection of explosives, chemical threats, and narcotics. This HSI system employs a liquid-crystal tunable filter that allows real-time automated detection and display of threats. We report on the next generation Aperio using improved optics for longer standoff distances and ChemImage's next generation Multi-Conjugate Filter (MCF) to increase sensitivity and detection speed. An optional tripod mounting with a motorized head is available for longer-range standoff applications such as hasty checkpoint or vehicle inspection. Basic software is extended to include additional features including a multi-target display function, automatic threshold determination, and an automated detection recipe capability for expanding threat library.

CISS will discuss application of the sensing technology to Homeland Security and Law Enforcement for standoff detection of homemade explosives and illicit drugs and their precursors in vehicle and personnel checkpoints. Additionally, Aperio may assist in revealing illicit drug manufacturing by detecting the presence of drugs and/or their precursors. Data will be presented that support the use of Aperio for explosive and drug screening at vehicle and personnel checkpoints as well as screening for explosives and drugs at suspected clandestine manufacturing facilities.

9073-27, Session 5

Bottled liquid explosives scanning by near infrared

Hideo Itozaki, Hideo Sato-Akaba, Osaka Univ. (Japan)

Airport security still limits for the passengers to bring their own bottled liquid in the airport, because no liquid scanner has been authorized to be used at the security in the airport. However, there are some demand to relax this limitation by using a bottle scanner from the passengers and security officers.

There are some bottle scanners that have been developed by using technologies of X-ray, IMS, Raman scattering, so on.

Here we have developed it by using near infrared. Absorption of water is quite high at more than one micro of light wave length. Absorption of color in the bottle and liquid is located in less than 0.5 micron of light wave length. So that we used near infrared with 0.5 to 1 micron of wave length. Not only clear liquid such as water but also dark one such as coke, coffee, and red wines can be identified easily even in dark black bottles. No safety regulation limits to instate this device in the airport, because of no using harmful X-ray or laser.

This has quite high detection rate and low alarm rate because it has numerous liquid data and can identified the liquid in the bottles clearly. It need less than a second to check a bottle and its size is so compact and easy handling and low financial loading to be introduced. It must be one of the strongest candidates for bottled liquid scanner in the airport.

9073-28, Session 5

Detecting explosive substances by the IR spectrography

Jaana R. Kuula, Heikki J. Rinta, Ilkka Pölönen, Hannu-Heikki Puupponen, Univ. of Jyväskylä (Finland); Tuomas Teravainen, Finnish Police (Finland); Marko Haukkamaki, Finnish Air Force (Finland)

There is a wide need for fast and safe detection methods of explosive substances both before and after actualized explosions. This article describes the detection of some selected explosive substances by the ATR FTIR spectrometer and by IR hyperspectral imaging devices. The IR spectrometers give accurate analyzing results, whereas hyperspectral

imagers can detect and analyze desired samples without touching the suspected target at all. In the controlled tests TNT, dynamite, PENO and some nitrates were at first analyzed as pure substances with the ATR FTIR spectrometer and with SWIR and MWIR cameras. After three controlled explosions also the residues of TNT, dynamite and PENO were analyzed with the same IR devices. The experiments were performed in arctic outdoor conditions and the residues were collected on ten different surfaces. The test results indicate that the IR spectrography is a promising detection method for explosive subjects.

9073-29, Session 6

Fate and effects of trace particulate explosives

Viet Nguyen, Robert Furstenberg, Nora C. Carr, Rachel C. McGill, Michael R. Papantonakis, Christopher A. Kendziora, R. Andrew McGill, U.S. Naval Research Lab. (United States)

When handling explosives, explosive devices, or related surfaces, the hands become contaminated with particles of explosives. Subsequent contact actions result in particle depositions and crushing on a surface within a fingerprint. The physicochemical characteristics of these particles are of particular importance to trace detection applications in DOD or DHS arenas. The longevity or stability of explosives particles on a substrate is a function of particle geometry, ambient temperature, airflow, relative humidity, condensation, inclusion chemicals, incident light and, in some instances, the substrate itself. In this work we deposit particles of explosives at trace levels by different techniques including sieving, inkjetting and pipetting, and monitor their sublimation by photo/video-microscopy. We compare and contrast the effect of deposition technique on particle fabrication and subsequent sublimation or related effects influencing particle lifetime. Various hypotheses will be presented to explain observed differences with supporting data. Analysis of 2D microscopic images is used to compute and track particle size and geometrical characteristics as functions of time and experimental test conditions. 3D particle imaging, GCMS or UV-visible spectrophotometry are used to provide supporting confirmation to the 2D image analysis. In this preliminary work a limited set of test conditions were used including variable airflow rates and fixed humidity, temperature and substrate type.

9073-30, Session 6

The external aerodynamics of canine olfaction and implications for improved vapor sampling and detection

Matthew Staymates, National Institute of Standards and Technology (United States)

An investigation of the external aerodynamics of canine olfaction is presented. Extending previous work done by Settles (2002) and Craven (2010), we have developed an anatomically-correct artificial dog nose, modeled from a female Labrador Retriever and fabricated using a 3D printer, that sniffs with realistic flow rates and frequencies. Flow visualization experiments using schlieren imaging enable real-time examination of the dogs remarkable ability to sample vapors from extended distances. During exhale, a turbulent air jet emanates from each nostril and entrains fluid from ahead of the nose, sometimes at a distance of many tens of centimeters. This vapor is now readily available for inhalation, during which the nose now acts as a potential flow inlet. This exhale/inhale cycle is repeated during active sniffing at a frequency of around 5Hz. We have learned that the dog is an active aerodynamic sampling system, utilizing fluid dynamics to increase its aerodynamic reach and sample vapors at increasingly large distances.

As a form of biomimicry, we are now utilizing bio-inspired design principles from the dog and applying them to current- and next-generation vapor sampling technology. This presentation will show many flow visualization examples of canine olfaction, and results from the biomimicry experiments that demonstrate improvements in vapor sampling of commercially-available explosives and narcotics vapor samplers by making them “sniff” instead of just inhale.

GS Settles, et.al. The External Aerodynamics of Canine Olfaction. A chapter in Sensors and Sensing in Biology and Engineering, ed. F.G. Barth, J.A.C. Humphrey, and T.W. Secomb, Springer, Vienna & NY, 2002.

BA Craven, et.al. The fluid dynamics of canine olfaction: unique nasal airflow patterns as an explanation of macrosmia. J.R. Soc. Interface, 7, 2010

9073-31, Session 6

Observation of atomic carbon during photodissociation of nitrotoluenes in the vapor phase

Hergen Eilers, Helena Diez-y-Riega, Washington State Univ. (United States)

When solid nitro-containing explosive materials are photodissociated, vibrationally-excited NO molecules are formed. Laser-induced fluorescence spectroscopy has been used by several groups to detect these molecules and proposed to use them as indicators for the presence of explosives. However, energy transfer from laser-excited nitrogen can potentially interfere with this particular detection process. Besides the emission from NO molecules, we have recently observed emission from atomic carbon during the photodissociation of mononitrotoluenes (MNTs) and dinitrotoluenes (DNTs) in the vapor phase. Comparing the intensities of distinct emission peaks with intensities expected from the Franck-Condon factors allows us to identify the presence of atomic carbon. Time-resolved fluorescence spectroscopy of the atomic carbon emission allows us to differentiate between MNTs and DNTs. The emission from atomic carbon in MNTs is observed for gate delays up to about 500 ns. The DNTs show emission from atomic carbon for gate delays of up to at least 1500 ns. The presence of carbon is also confirmed by carbon deposits inside the sample chamber. EDS and Raman spectroscopy of these deposits clearly show the presence of carbon. The spectroscopic signal from atomic carbon in the vapor phase is observed at concentrations as low as 10 ppt. Based upon the observed S/N, detection at even lower concentrations appears feasible. Several non-nitrotoluene molecules including nitrobenzene, benzene, toluene, and CO2, have been tested under identical conditions, but do not show any carbon emission. Energy transfer from laser-excited nitrogen and/or delayed photodissociation may be responsible for the observation of atomic carbon at long gate delays.

9073-32, Session 6

Analysis of nonstandard and home-made explosives and post-blast residues in forensic practice

Marek Kotrl?, Institute of Criminalistics Prague (Czech Republic) and Charles Univ. in Prague (Czech Republic); Ivana Turková, Institute of Criminalistics Prague (Czech Republic)

Nonstandard and home-made explosives can constitute a considerable threat as well as potential material for terrorist activities. Number of cases capturing the substances is not negligible and a substantial amount of brisant explosives is often seized. Chemicals are also found during investigation of other types of criminality - for example drug related crimes (clandestine /home-made/ drug labs, in-door growing rooms, etc.). Findings covering these substances pose a considerable risk to police officers involved because a type and characteristics of compounds seized are not clear, not excluding even organic peroxides, and the like. Mobile analytical devices, particularly Raman, or also FTIR spectrometers are used for initial detection.

Various sorts of moderants (deterrents, phlegmatizers) aiming to decrease sensitivity of explosives were tested, some kinds of low viscosity lubricants yielded very good results. If the character of the substance allows further

examination, phlegmatizated samples are taken, in the amount of approx. 0.3 g for laboratory analysis. TLC has still proved itself for laboratory screening; next, combinations of FTIR, Raman spectrometry, LC MS, GC MS and others are used. XRD techniques capable of a direct phase identification of a crystalline matter, also in mixtures, have greatly proved themselves for inorganic and organic phases. SEM-EDS/WDS, XRF, micro XRF methods are standardly utilized for inorganic phase. In analysing post-blast residues, techniques allowing analysis at the level of separate partials, not the overall composition in a mixed sample, are of key importance.

9073-33, Session 6

Design and validation of inert homemade explosive simulants for x-ray-based inspection systems

Anthony A. Faust, Defence Research and Development Canada, Suffield (Canada); Sabatino Nacson, VisionTec Systems (Canada); Bruce Koffler, VisionTec Systems Ltd. (Canada); Eric Bourbeau, Optosecurity Inc. (Canada); Louis Gagné, Robin Laing, John Anderson, Defence Research and Development Canada, Suffield (Canada)

Transport Canada (TC), the Canadian Armed Forces, and other public security agencies have an interest in the assessment of the potential utility of advanced explosives detection technologies to aid in the detection and interdiction of commercial grade, military grade, and homemade or improvised explosives (HME or IE). The availability of suitable, non-hazardous, non-toxic, explosive simulants is of concern when assessing the potential utility of such detection systems; lack of simulants limits the training opportunities, and ultimately the detection probability, of security personnel using systems in the field. While simulants for commercial and military grade explosives are available for a wide variety of detection technologies, the design and production of materials to simulate improvised explosives has not kept pace with this emerging threat.

With the support of TC, Defence Research and Development Canada (DRDC), VisionTec Systems, and Optosecurity engaged in an effort to develop inert, non-toxic X-ray-relevant simulants for IE materials such as ammonium nitrate (AN), potassium chlorate (PC), and triacetone triperoxide (TATP).

These simulants were designed to mimic key X-ray interrogation-relevant material properties of real improvised explosives, principally their bulk density and effective atomic number.

Different forms of the simulants were produced and tested, simulating the different explosive threat formulations that could be encountered by front line security workers. These simulants complied with safety and stability requirements, and as best as possible matched form and homogeneity.

Comparative evaluations of both simulants and real explosives were conducted both by VisonTec, on a Voti X-ray system, and by Optosecurity on data collected by DRDC on a Smith's HS6046si X-ray Interrogation System .

This paper outlines the research program, simulant design, and validation.

9073-34, Session 7

Discriminating bacterial spores from inert airborne particulate matter by classification of optical scattering patterns

Giovanni Franco Crosta, Univ. degli Studi di Milano-Bicocca (Italy); Yongle Pan, Gorden Videen, U.S. Army Research Lab. (United States)

The discrimination of aerosolized biological threat, represented by bacterial spores, from harmless, respirable particles is a basic need in environmental monitoring. A by now well-known experimental method, TAOS (Two-dimension Angle-resolved Optical Scattering), is capable of detecting single, airborne material particles and collecting the corresponding scattering pattern. The pattern covers a wide solid angle and is produced with the illumination of a single monochromatic laser pulse. TAOS patterns from microspheres of known materials, from single bacterial spores, soot aggregates and outdoor sampling have been collected and stored by the thousands. Although the recognition of TAOS patterns remains a challenge, recently developed algorithms based on machine intelligence have discriminated bacterial spores from all other materials within the limits of 20% false negatives and less than 11% false positives. Ongoing work is aimed at reducing false alarms on either side. Two issues are being addressed. 1) Quantitative assessment of the interfering (a.k.a. "confounding") role which diesel soot aggregates play: the classifier in the current version is applied and a pattern rejection threshold is varied within limits suggested by detector noise statistics. 2) Simultaneous processing of two regions of interest in the TAOS pattern: this amounts to complexifying the data structures in the algorithm and relying on pattern symmetries. The corresponding results will be compared with previous ones and possibly justified.

9073-35, Session 7

Modeling fluorescence of bioaerosols using improved estimates of concentrations and optical properties of the relevant molecules

Steven C. Hill, Chatt C. Williamson, Yongle Pan, U.S. Army Research Lab. (United States); Joshua L. Santarpia, Sandia National Labs. (United States)

The development fluorescence-based instruments for monitoring bioaerosols (bacteria, pollens, fungal spores, etc.), and the use of these instruments in monitoring and studying bioaerosols have been reported in many journal articles. However, there have been few reports of mathematical modeling of fluorescence of bioaerosols, and much of this modeling reported has been overly simplistic, for example, including tryptophan as the only fluorescing and the only absorbing molecule. A recent paper (Hill, et al., "Fluorescence of bioaerosols: mathematical model including primary fluorescing and absorbing molecules in bacteria," Opt. Express, 21, 22285-22313 (2013)) describes a mathematical model for calculating bioaerosol fluorescence. It includes concentrations, absorptivities and fluorescence quantum efficiencies of relevant absorbing (e.g., RNA) and fluorescing (e.g., tryptophan) molecules that are in the range of those in bioaerosols composed of bacteria or proteins. The bioparticles are treated as homogeneous spheres. Here we use that mathematical model to calculate of the size dependence of the UV-excited fluorescence from model bioaerosols composed of bacteria and of pure proteins. The variation of the particle's fluorescence with particle size is typically needed in fluorescence-based bioaerosol detectors and in calibrating such detectors. We also present new calculations illustrating how the water content of a model bioaerosol particle affects the dependence of the fluorescence on particle size.

9073-36, Session 7

Atmospheric aerosol sensing using rotating drum impactor-dual wavelength UV laser-induced fluorescence spectra

Chuji Wang, Mississippi State Univ. (United States); Yongle Pan, Deryck James, Alan Wetmore, U.S. Army Research Lab. (United States); Brandon Redding, Yale Univ. (United States)

Atmospheric aerosols pose significant concerns for global climate, air quality, and human health. Chemical compositions in atmospheric aerosols also changes with time, size, and geological and meteorological situations. It remains a challenge to indentify aerosol compositions and monitor changes with time. We report on size- and time-resolved atmospheric aerosol

analysis using dual wavelength UV laser induced fluorescence (LIF) spectra combined with an 8-stage rotating drum impactor (RDI) for continuous collection of aerosol particles over a 3-week period from Djibouti. Off-line LIF measurements were achieved by directly shining a laser beam onto the particles impacted on a RDI strip with a spatial resolution of 1.2 mm, corresponding to a time resolution in the aerosol sampling of 3.6 hrs. Excited by a 263 nm or 351 nm laser, more than 2000 pairs of LIF spectra within a 3-week aerosol collection time period were obtained from the eight individual RDI strips that collected particles in eight different sizes ranging from 0.09 to 10 μm. Based on the known aerosol UV fluorescence cluster database in the US, the Djibouti LIF spectra were found to be dominated by Clusters 2, 5, and 8 (peaked at 330, 369, and 475 nm) when excited at 263 nm and by Clusters 1, 2, 5, and 6 (peaked at 390 and 458 nm) when excited at 351 nm. The possible chemical compositions contributed to these fluorescence clusters will be discussed. Some of the LIF spectra show clear size- and time-dependent behavior. Advantages, limitations, and future developments of this new aerosol sensing technique will also be discussed.

9073-37, Session 7

Standoff detection: classification of biological aerosols using laser-induced fluorescence (LIF) technique

Anita Hausmann, Frank Duschek, Thomas Fischbach, Carsten Pargmann, Jürgen Handke, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); Sergey Babichenko, Laser Diagnostic Instruments AS (Estonia)

The challenges of detecting hazardous biological materials are manifold: Such material has to be discriminated from other substances in various natural surroundings. The detection sensitivity should be extremely high. As living material may reproduce itself, already one single bacterium may represent a high risk. Of course, identification should be quite fast with a low false alarm rate. Up to now, there is no single technique to solve this problem. Point sensors may collect material and identify it, but the problems of fast identification and especially of appropriate positioning of local collectors are sophisticated. On the other hand, laser based standoff detection may instantaneously provide the information of some accidental spillage of material by detecting the generated thin cloud. LIF technique may classify but hardly identify the substance. A solution can be the use of LIF technique in a first step to collect primary data and – if necessary- followed by utilizing these data for an optimized positioning of point sensors.

We perform studies on an open air laser test range at distances between 20m and 135m applying LIF technique to detect and classify aerosols. In order to employ LIF capability, we use a laser source emitting two wavelengths alternatively, 280nm and 355nm, respectively. Moreover, the time dependence of fluorescence spectra is recorded by a gated intensified CCD camera. Signal processing is performed by dedicated software for spectral pattern recognition. The direct comparison of all results leads to a basic classification of the various compounds.

9073-38, Session 7

Consumer of concern early entry program (C-CEEP) biological surveillance: protecting against the suicidal biological warfare host

Janet Fish, Capella Univ. (United States)

The ability to detect both entry into the United States of a Suicidal Biological Warfare Host Agent during the initial stages of the incubation period is critical for effective National Security containment. Preventing, containing, or eliminating disease threats are impossible if public authorities cannot recognize and act against threats in a timely manner. The C-CEEP {Consumer of Concern Early Entry Program} represents another attempt at bringing together the two independent worlds of public health and security using National Security as the denominator for the common good. C-CEEP is a living Biological Surveillance program ideology that would include detection measures using Thermal Imagining currently in use in South Korea, Turkey, Greece, and Saudi. The ultimate goal is to detect human carriers acting as Suicidal Warfare Agents upon entry into United States using maritime ports of entry. The final concept of the program is to be adaptable at any port of entry via land, air, or sea.

Primary goals are the identification of individuals; data capture of key indicators of Host Agents using current or developing software that can be incorporated into existing information sharing systems located throughout the United States for both Public Health and Law Enforcement tracking and surveillance. This paper defines the problem, addresses hardened Complex Systems; identifies critical stakeholders via power/ influence methodology, along with transformational and adaptive leadership applications required for success.

9073-39, Session 7

A microfluidic platform with integrated arrays for immunologic assays for biological pathogen detection

Richard Klemm, Claudia Gärtner, Sebastian Schattschneider, Holger Becker, Nadine Hlawatsch, microfluidic ChipShop GmbH (Germany); Sandra Julich, Herbert Tomaso, Friedrich-Loeffler-Institut (Germany)

The ability to integrate complete assays on a microfluidic chip helps to greatly simplify instrument requirements and allows the use of lab-on-a-chip technology in the field. A core application for such field-portable systems is the detection of pathogens in a CBRN scenario such as permanent monitoring of airborne pathogens, e.g. in metro stations or hospitals etc.

An immunological assay was chosen as technology for the pathogen detection. The core of the overall approach was the realization as lab-on-a-chip system enabling an easy handling of the sample in an automated manner. The immunological detection takes place on an antibody array directly implemented in the microfluidic network. Different immobilization strategies will be presented showing the performance of the system. Central elements of the consumable microfluidic device like fluidic interface, turning valves, liquid introduction and waste storage, as well as the architecture of measurement and control fluidic network will be introduced.

Detection limits in the upper pM range within less than 30 minutes were achieved and assays for the detection of Francisella tularensis and Yersinia pestis will be presented.

An important feature of the integrated lab-on-a-chip approach is that all waste liquids remain on chip and contamination risks can be avoided.

9073-40, Session 7

Detection and monitoring of CWA and BWA using LIBS

Lars Landström, Anders Larsson, Per-Åke Gradmark, Lillermor Örebrand, Per O. Andersson, Pär Wästerby, Torbjörn Tjärnhage, FOI (Sweden)

Results related to laser induced breakdown spectroscopy (LIBS) as an analytical tool in applications for CWA and BWA detection/monitoring will be presented and discussed. A real-time aerosol analysis set-up using LIBS on single μm-sized particles (sampled from ambient air to a particle stream) has been developed and evaluated. Here, a two-stage triggering unit ensures a high hit-rate of the sampled aerosol particles and the optical emission from the laser induced plasma is collected and coupled into an echelle spectrometer equipped with an intensified CCD detector. Each CCD image (echellogram), optimally originating from a single μm-sized particle, is then analyzed and the result can be treated by an alarm algorithm using database matching via multivariate statistics. The system

has been tested both in controlled atmospheres (aerosol chamber/wind tunnel) as well as in real-life settings using different simulant agents and interferents. Furthermore, different surfaces have been analyzed by LIBS to obtain information about residues of organophosphates on (or within) these surfaces. Depth analysis has been performed to monitor diffusion and penetration behavior of neat CWAs and simulant chemicals by following the intensity of phosphorous emission lines in single shot LIBS spectra as function of number of laser pulses. In addition, LIBS analysis was also performed after decontamination procedures, and elution from, certain paint systems. For some paint systems, P emission lines were still observed after the chemical treatment. Possibilities and challenges associated with the different set-ups and applications will be discussed in connection with the presented results.

9073-41, Session 7

Silver nanorods modified filters for rapid on-chip pre-concentration and SERS sensing of bacterial whole cells

Jing Chen, Xiaomeng Wu, Yaowen Huang, Yiping Zhao, The Univ. of Georgia (United States)

Surface enhanced Raman spectroscopy (SERS) has been increasingly explored in whole cell sensing including pathogenic bacteria. The label-free SERS detection schemes are particularly attractive for their simplicity, low cost, and ability to reveal intrinsic spectral fingerprints on the cells. Unfortunately, their applicability has been limited by the low detection sensitivity. In this study, we have successfully deposited silver nanorod (AgNR) arrays onto cellulose- and anodized aluminum-based filter membranes with proper pore sizes (0.2 μm) using oblique angle deposition (OAD). The novel AgNR filter substrates allow continuous filtration of liquid contents and accumulation of bacterial cells on the SERS-active sensing surface. Utilizing such a platform, we have obtained reproducible SERS spectra from Eschericia coli, whose intensity increases as the cells accumulate on the AgNR filters. Under continuous filtration, the lower limit of detection (LOD) is reduced from 10^8-10^9 CFU/mL to 10^5-10^6 CFU/mL within 10-15 min, when the sampling volume increases from 10 μL to 10 mL. Meanwhile, the sample drying time is shortened from 1-2 h under laminar air flow on non-porous AgNR substrates to less than 1 min on filter AgNRs thanks to vacuum filtration. The on-chip cell pre-concentration circumvents prolonged cell culturing steps, and in conjunction with shortened sample drying time, the new AgNR filter substrates can significantly reduce total assay time while improving the detection sensitivity. In addition, the AgNR filters show great potential as a core element for facile, automated sampling, pre-processing, pre-concentration, and direct sensing devices for whole cell SERS detection.

9073-42, Session 7

Portable diagnostic kit for the detection of Bacillus anthracis in ultra-low resource environments

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Anthrax poses a significant threat to US National Security as demonstrated by the 2001 terrorist attacks targeting the US Postal Service and Hart Building. The causative agent, Bacillus anthracis, is ubiquitous worldwide. More importantly, it is found in countries harboring terrorists.

Anthrax outbreaks commonly occur in livestock. Consequently, the agent is routinely isolated, propagated, and maintained in laboratories by indigenous populations to diagnose the disease. This practice drastically increases laboratories' repositories of B. anthracis, and escalates the risk that the agent can be stolen for nefarious purposes. Moreover, it enhances the capabilities of laboratory personnel to produce pure isolates.

To mitigate these risks, we have developed a robust portable diagnostic device for detection of bacteria in ultra-low resource environments that is low cost (<$5/assay), requires no power, instrumentation or equipment to operate, no cold chain to maintain efficacy, and can be operated by individuals with little to no technical training.

The self-contained credit-card sized device employs micro-culture methods to amplify bacteria prior to downstream lateral flow assay, improving detection limit by 4+ orders of magnitude (positive detection from 100 spore initial inoculum, Ames strain). Additionally, the device utilizes chemical and biological means to sterilize the contents following assay. Self-decontamination minimizes the potential for malicious use of the bacterial sample following assay and reduces the need for experienced staff to isolate the organism in the laboratory.

Finally, this platform is readily adaptable for detection of other bacterial agents including Burholderia pseudomallie, food borne pathogens, and drug resistant Staphylococcal and Streptococcal organisms.

9073-43, Session 7

Measurement of 100 B. anthracis Ames spores within 15 minutes by SERS at the US Army Edgewood Chemical Biological Center

Stuart R. Farquharson, Chetan S. Shende, Wayne W. Smith, Real-Time Analyzers, Inc. (United States); Jason A. Guicheteau, U.S. Army Edgewood Chemical Biological Ctr. (United States)

The 2013 use of sarin gas in Syria is a reminder that chemical and biological warfare is an ever present danger. While there has been substantial effort since the anthrax attack of 2001 to develop analyzers to detect this and other biological warfare agents, the analyzers remain either too slow, produce high false-positive rates, lack sensitivity, or cannot be fielded. In an effort to develop an analyzer that has the required speed, selectivity, sensitivity, and field robustness, we have been developing a surface-enhanced Raman spectroscopy system. Here we describe the use of silver nanoparticles functionalized with a short peptide to selectively capture Bacillus anthracis spores and produce SER scattering. Specifically, measurements of 100 B. anthracis spores in less than 15 minutes performed at the US Army's Edgewood Chemical Biological Center will be presented. The measurements provide a basis for the development of systems that can detect spores collected from the air or water supplies with the potential of saving lives during a biological warfare attack.

9073-44, Session 8

Utilization of advanced clutter suppression algorithms for improved standoff detection of radionuclide threats

Bogdan R. Cosofret, Kirill Shokhirev, Phillip Mulhall, Physical Sciences Inc. (United States); David Payne, Raytheon Integrated Defense Systems (United States); Bernard Harris, Raytheon Co. (United States)

Technology development efforts seek to increase the capability of detection systems in low Signal-to-Noise regimes encountered in both portal and urban detection applications. We have recently demonstrated significant performance enhancement from existing Advanced Spectroscopic Portal (ASP) and Standoff Radiological Detection (SORDS) systems through the use of new advanced detection and identification algorithms. The Poisson Clutter Split algorithm, developed under DNDO sponsorship, has been integrated with ASP and SORDS units and evaluated in field trials. PCS is a novel approach for radiological background estimation that improves the detection and discrimination capability of medium resolution detectors. The algorithm processes energy spectra and performs clutter suppression, yielding de-noised gamma-ray spectra that enable significant enhancements in detection and identification of low activity threats with spectral target

recognition algorithms. The performance is achievable at the short integration times (~0.5sec) necessary for operation in a high throughput and dynamic environment. We present a quantitative analysis of algorithm performance against data collected in several environments with embedded check sources. We show that the algorithm achieves a high probability of detection/identification with low false alarm rates under low SNR regimes. For example, utilizing only 4 out of 12 NaI detectors currently available within an ASP unit, PCS processing demonstrated P_d,ID > 90% at a CFAR = 1 in 1000 occupancies against weak activity (<8μCi) and shielded sources traveling through the portal at 30 mph. This vehicle speed is a factor of ~6 higher than was previously possible and results in significant increase in system throughput.

9073-45, Session 8

Image characterization metrics for large field of view muon tomography

Michael J. Sossong, Decision Sciences International Corp. (United States); Weidong Luo, Joel Kindem, Matt Steiger, Gemini Design, LLC (United States)

Muon tomography uses naturally occurring cosmic rays to detect nuclear threat in containers. Currently there is no systematic metrics for large field of view muon tomography. We propose a set of image characterization metrics to quantify the imaging performance of large field of view muon tomography. These include tests of spatial resolution, uniformity, contrast, signal to noise ratio (SNR) and spillover.

Simulation phantoms and analysis methods were developed to evaluate metric applicability. Spatial resolution was determined as the FWHM of the point spread function in X, Y and Z axis for 2.5cm tungsten cubes. Uniformity was measured by drawing a volume of interest (VOI) within a large water phantom. VOI size was 160cm x 240cm x 40cm and voxel size was 40cm x 40cm x 40cm. Uniformity was defined as the standard deviation of voxel values divided by the mean voxel value. Contrast was defined as the peak signals a set of tungsten cubes (widths range from 50cm, 25cm, and 10cm to 5cm) divided by the mean water background. SNR was defined as the peak signals of cubes divided by the standard deviation of the water background. Spillover described thickness increases for a set of 2 cm thick tungsten plates (widths range from 50cm, 25cm, and 10cm to 5cm) horizontally placed. It was defined as the FWHM of vertical spread function for the plate.

These image metrics provided a useful tool to quantify the basic image physics properties for muon tomography. Final results will be reported in the conference.

9073-46, Session 8

Muon tomography imaging improvement using optimized limited angle data

Michael J. Sossong, Decision Sciences International Corp. (United States); Joel Kindem, Weidong Luo, Matt Steiger, Gemini Design, LLC (United States)

Image resolution of Muon Tomography is limited by the range of zenith angles of muons and the flux rate at sea level. Low flux rate limits the use of advanced data rebinning and processing techniques to improve image quality. By optimizing the limited angle data, however, the image resolution can be improved.

GEANT simulated data and data acquired on a commercial system were grouped to subsets using the zenith angle, and the total muon tracks in each zenith angle group were counted. For each subset, a volume image was reconstructed from scattering angle data.

The simulation data had muons distributed with a cosine-squared distribution off zenith, the expected natural flux of muons. The zenith angle distribution of the muons of the acquired data was the natural distribution, partially limited in zenith angle coverage by detector acceptance. Image quality were compared for the complete dataset and various subsets of incoming zenith angles. In both simulation and measurement studies, image resolution was better in the vertical direction for subsets with higher zenith angles, and better in the horizontal plane for more vertical muons. The image from the overall data could be recovered from recombination of subset images.

Results show that the acquired data can be grouped into different limited angle data sets for optimized image resolution in desired directions. Use of multiple images with resolution optimized in different directions can improve overall imaging fidelity.

9073-47, Session 8

Improved nuclear material detection using joint neutron and gamma ray analysis

Amanda C. Madden, The Univ. of New Hampshire (United States)

We present the test results of a neutron/gamma-ray imaging spectrometer for the identification and location of radioactive and special nuclear materials. Radioactive materials that could be fashioned into a radiation dispersal device typically emit gamma rays, while fissile materials such as uranium and plutonium emit both neutrons and gamma rays via spontaneous or induced fission. The simultaneous detection of neutrons and gamma rays is a clear indication of the presence of fissile material. The instrument works as a double-scatter telescope, requiring a neutron or gamma ray to undergo an interaction in two detectors to be considered a valid event. While this requirement reduces the detector efficiency, it yields information about the direction and energy of the incident particle, which is then used to reconstruct an image of the emitting source. Because of this imaging capability background events can be subtracted, decreasing the number of events required for high confidence detection and thereby greatly improving its sensitivity. The instrument is optimized for the detection of neutrons with energies from 1-20 MeV and gamma rays from 0.4 to 10 MeV. Images and energy spectra for neutron and gamma rays are reported for several sources including depleted uranium and plutonium. The Receiver Operating Characteristic (ROC) curve helps to characterize an instruments ability to differentiate between particles detected from radioactive and nuclear materials, and that from natural background radiation. The ROC curve gives the relationship between a certain number of detected events being a true indication of a source, and the probability that this number of events constitutes a false alarm. The superior background rejection of the NSPECT instrument significantly improves the ROC curve within the detection of a single species. The ROC curve improves even further when analyzing the neutron and gamma ray data in tandem, in a two dimensional data space. This paper will show the response of the NSPECT instrument to common neutron and gamma ray sources as well as projections of the instrument's response to samples of weapons grade and reactor grade plutonium.

9073-48, Session 8

Operator-based integration of information in multimodal radiological search mission with applications to anomaly detection

John J. Benedetto, Alexander Cloninger, Wojciech Czaja, Timothy Doster, Univ. of Maryland, College Park (United States); Kevin Kochersberger, Virginia Polytechnic Institute and State Univ. (United States); Thomas L. McCullough, Lance K. McLean, National Security Technologies, LLC (United States)

Successful performance of the radiological search mission, which is dependent on a mixture of signals from a heterogeneous sensor network, is strongly correlated with the reliability and efficiency of anomaly detection. Examples of modalities in use include EO imagery and gamma radiation data arising from aerial overflights. In addition, further information, such

as, e.g., elevation data or spatial proximity may be used to enhance the performance of autonomous multimodal acquisition systems. This creates a complex information structure, which requires new tools and methods to analyze and extract the relevant information.

State of the art techniques in processing and exploitation of complex information manifolds rely on diffusion kernels and their corresponding operators, which give rise to effective schemes for data organization, classification, and anomaly detection. Such techniques raised to prominence in recent years, with several methods relying on the properties of Laplacian on data-dependent graphs.

We propose to redefine the approach to data organization derived from a single diffusion process. In place of a single process, we propose to consider families of data-dependent Laplace and Schroedinger operators on joint data graphs, which shall be integrated by means of appropriately designed fusion metrics, fusion graphs, and fusion operators. The added computational complexity, which is inherent to the resulting integrated network, is dealt with by utilizing novel ideas from machine learning and harmonic analysis: compressed sensing and random projections, landmarks and Nystroem extensions, dimensionality reduction and fast approximate neighborhood constructions. We exploit linear mixing and endmember extraction in this new representation of joint data, for target and anomaly detection.

9073-49, Session 8

Wavelet-assisted variance reduction anomaly detection

Thomas L. McCullough, National Security Technologies, LLC (United States) and Univ. of Maryland (United States); Matthew R. Kiser, National Security Technologies, LLC (United States); Lance K. McLean, National Security Technologies, LLC (United States) and Univ. of Maryland (United States)

Radiological search depends on the successful recognition of radiological anomalies in the dynamic background.

Anomaly detection may then trigger the effort of identification of the source of the radiological anomaly, for determination of the threat potential and characteristics. Often radiological search operations must be carried out in challenging environments that lead to unavoidable decline in the spectral quality due to gain instabilities and resolution degradation. Furthermore, applications in the stand-off and aerial regimes often exhibit poor statistics which can present challenges to established anomaly detection schemes. Fortunately, the recognition of radiological anomalies is a much simpler problem than isotope identification, and the two processes are not not intrinsically linked. Thus anomaly detection may in principle proceed effectively even when when the spectral quality is less than ideal. We provide a general approach for real time anomaly detection, that is resistant to search system detector imperfections and avoids the limitations of any source or template library. The result is a method that provides immediate, easily interpreted and actionable user feedback. The algorithm uses an idea based on the continuous wavelet transform for variance reduction and the formation of an expectation vector from recent measurements to drive an evaluation of the deviation between the current measurement and the expectation using methods from linear algebra. The generality and simplicity of these ideas yield an algorithm which is flexible and easily applied, while being quite effective. To demonstrate the efficacy of the algorithm, results from the application of the algorithm to real world data collected outside of the controlled laboratory environment are presented.

9073-50, Session 8

Spectral clustering for aerial radiological surveys via nonlinear dimension reduction

Thomas L. McCullough, Lance K. McLean, National Security Technologies, LLC (United States) and Univ. of Maryland (United States)

Due to the number of spectra that comprise a typical data set, the analysis of aerial radiological survey data has traditionally relied on relatively coarse spectral processing methods. For emerging problems in consequence management, non-proliferation and nuclear forensics, however, the analysis of very large aerial data sets that exhibit a high degree of spectral complexity is desired. Furthermore, the recent experience of the DOE/NNSA Aerial Measuring Systems team during the Fukushima Dai-ichi Nuclear Power Plant incident underscored the urgent need for more powerful data processing schemes. Although it is possible to adapt and apply standard dimension reduction methods such as Principle Component Analysis or, equivalently, Singular Value Decomposition to the aerial data, classifications arising from these methods remain relatively crude. Additionally, the idiosyncracies of the gamma-ray spectra collected from aerial platforms confound modern clustering methods such as k-means. We have developed an algorithm that applies the method of Laplacian Eigenmaps to spectral ensembles that allow for clustering of the data via standard techniques. The method we have devised is entirely data-driven and unsupervised. This method reveals far more subtle features in the data and allows for much greater insights in the analysis. The re-casting of the aerial gamma ray spectra as data graphs also opens the door for true data fusion applications. Several relevant examples of the clsutering results, and their interpretations will be provided.

These examples include data from the Fukushima response and the nuclear weapon debris fields at the Nevada National Security Site (formerly the Nevada Test Site).

9073-51, Session 8

Algorithms for directional ionizing radiation detection systems

Lance K. McLean, National Security Technologies, LLC (United States) and Univ. of Maryland (United States); Matthew R. Kiser, Thomas L. McCullough, National Security Technologies, LLC (United States)

Directional ionizing radiation detection systems based upon the self-occlusion concept represent an attractive option for radiological search and monitoring systems due to their relative simplcity, potential durability and economy. The current generation of these sensors use relatively simplistic geometric decompositions of the count rate profile to determine the source azimuth in the detection plane. A multiplet of such systems can also be used to locate a source in two dimensions in as little as one data acquisition cycle in an uncomplicated way. However, the differential attenuation of the source flux by the specific geometry of a self-occluding system gives rise to new and usable signatures. We have several novel approaches to leveraging both the gross count profile and unique spectral information provided by the multi-element system. Importantly, the high dimensionality of the data provides a wider feature space than is present in a sigle element system. This fact can, for example, significantly enhance the ability of such systems to perform anomaly detection. We proceed from a review of the most basic source localization algorithms to multi-sensor system methods to include those for heterogeneous sensor arrays. We then show examples from both simulated and real data of how occluding detection systems can be used to drive numerous analyses. Illustrations are given of how even systems with relatively poor resolution can be used to perform such things as source classification and multiple source tracking. We also show, using simulated detector responses how the choice of detector composition and configuration affects the algorithmic approach. Finally, opportunities for data fusion are highlighted as part of our ongoing efforts.

9073-52, Session 8

Nuclear detection and monitoring using plants electricity

Mohammad M. Islam, Univ. of Maryland, Baltimore County (United States); Wenze Xi, Thomas Jefferson National Accelerator Facility (United States); David J. Y. Feng, National Univ. of Kaohsiung (Taiwan); Fow-Sen Choa, Univ. of Maryland, Baltimore County (United States)

Plant electricity was discovered about 100 years ago. Until recent two decades, researchers started to notice that the electricity play a key role for plant's communications and defense. Recently, we have demonstrated a wound-generated electrical signal, up to a few hundred mV, can be produced and propagate through the whole plant. As plants defense reactions the wound signal will activate genes and induce subsequent molecular biology responses. In this study, we further investigate the electrical response of plants when they are under nuclear radiation. We discovered nuclear radiation could produce internal voltage gradient in living trees, resulting in measureable voltage and current signals. The results was measured by attaching one of electrodes to a lower branch, close to the roots and attaching the other one to an upper branch. During irradiating, trees were set up at 1-meter far from a NIST-certified 241AmBe neutron source (30 mCi). It will produce a neutron field of about 13 mrem/h, corresponding to an actual absorbed dose of ~ 1 mrad/h by assuming the tissue is primarily water content. Once the radioactive source is pulled up from a shielded container below the tree, the system potential starts to drop and in about 6-7 hours it drops down to -220mV, eventually stabilizing at around -250mV after 10 hours of radiation. We further have observed plant electricity changes caused by x-ray, gamma-ray, and beta-ray radiations. After the sources were removed, the terminal voltage recovered and eventually returned to the original value.

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9074-1, Session 1

Inverse synthetic aperture radar imaging for concealed object detection on a naturally walking person

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The problem of detection concealed threats under clothes on ground transport hubs and other places of mass gathering remains actual as such places remain targets of terror attacks. Unlike airports where thorough inspection involving body scanners and manual search is possible, bringing the same level of security to other transport systems remains a challenge. The paper addresses the issue of transport and infrastructure security by considering the concept of inverse aperture synthesis to such target like a naturally walking person. The vertical resolution in such ISAR system is achieved by a microwave antenna array while horizontal resolution obtained due to person's natural walking in perpendicular direction. The coherent processing of acquired radio signal and obtaining a synthetic radio image from not stationary target is possible by processing synchronous video that gives required trajectories of subject's parts, both limbs and clothes. The radio image can be obtained for an arbitrary moment by processing the accumulated radio signal and video sequence. The outlined concept was demonstrated on experimental data obtained with a system consisting of a vertical scanner with movable continuous wave radar and a stationary camera. Signal acquisition was performed by stop motion technique when the object of interest was moved in small steps, photographed and vertically scanned each time. The resulting radio images obtained for objects with simple geometric shapes with concealed inclusions are presented. The influence of positioning errors and integration time on resulting image was computationally assessed in typical geometry of sounding. Adaptation of the technique for passive sensors is also proposed in context of blur and noise mitigation.

9074-2, Session 1

Infrared polarimetric sensor for infrastructure protection

David B. Chenault, Joseph L. Pezzaniti, Polaris Sensor Technologies, Inc. (United States)

Measurement of the polarization content of a scene frequently offers additional contrast that is not readily apparent or is not measured at all with the conventional imager. An infrared imaging polarimeter measures one or more parameters of the polarization ellipse and also the conventional intensity. Such polarimetric imaging systems, particularly in the infrared, have shown significant promise for detection of otherwise hard to find objects. Polarization contrast often remains high during periods of zero thermal contrast and can successfully detect manmade targets in natural clutter, long after thermal equilibrium of the target with the background has been established. A number of potential applications for port and harbor security, fixed site protection, border control and other homeland security scenarios have been demonstrated using scientific polarimetric systems. Polarimetric imaging has seen significant advancement over the last decade and now small, real-time infrared polarimetric cameras are now available. In this paper, we describe such imaging polarimeter systems, show some preliminary results that demonstrate the enhanced contrast possible with such systems, and discuss ways in which this system could be integrated with existing infrastructure.

9074-3, Session 1

A key to success: optimizing the planning process

Hüseyin Türk, Kamil Karakaya, Harp Akademileri Komutanligi (Turkey)

By adopting The NATO Strategic Concept Document in 2010, some important changes in the perception of threat and management of crisis were introduced. This new concept, named ''Comprehensive Approach'', includes the precautions of pre-crisis management, applications of crisis-duration management and reconstruction phase of post-intervention management. NATO will be interested in not only the military options , but also political, social, economical and informational aspects of crisis. NATO will take place in all phases of conflict. Terrorism and the conflictions which occur outside the borders of NATO's nations are perceived as threat sources for peace and stability. In addition to conventional threats, cyber attacks which threaten network-supported communication systems, preventing applications for accessing to space that will be used in different fields of life, electronic warfare capabilities which can effect negatively are added to threat list as new threats. In the process in which is thought about military option, a harder planning phase is waiting for the decision makers of the NATO who struggle for keeping peace and security. Campaign planning process which depends on comprehensive approach, contains these steps: Situation awareness of battlefield, evaluation of the military intervention options, orientation, developing campaign plan, reviewing the plan and transition phases.1 To be successful in theater which is always changing with the technological advances, there has to be an accurate and timely planning on the table. So that, spending time for planning can be shown as one of the biggest problem. In addition, sustaining situational awareness which is important for the whole campaign planning process, technical command and control hitches, human factor, unable to determine the center of gravity of opponent in asymmetrical threat situations can be described as some of the difficulties in campaign planning. In this study, a possible air campaign planning process was analyzed according to comprehensive approach. The difficulties of planning were identified. Consequently, for optimizing a decision-making process of an air campaign, an optimized planning process was identified in a fictive command and control structure.

9074-4, Session 1

Fly eye radar or micro-radar sensor technology

Pavlo A. Molchanov, Compass Systems, Inc. (United States); Olha V. Asmolova, AETHER Inc. (United States)

To compensate for its eye's inability to point its eye at a target, the fly's eye consists of multiple angularly spaced sensors giving the fly the wide-area visual coverage it needs to detect and avoid the threats around him. Based on a similar concept a revolutionary new micro-radar sensor technology is proposed for detecting and tracking ground and/or airborne low profile low altitude targets in harsh urban environments. Distributed along a border or around a protected location (military facility and buildings, camp, stadium) small size, low power unattended radar sensors can be used for target detection and tracking, threat warning, pre-shot sniper protection and provides effective support for homeland security. In addition it can provide 3D recognition and targets classification due to its use of five orders more pulses than any scanning radar to each space point, by using few points of view, diversity signals and intelligent processing.

The application of an array of directional antennas eliminates the need for a mechanical scanning antenna or phase processor. It radically decreases radar size and increases bearing accuracy several folds. The proposed micro-radar sensors can be easy connected to one or several operators by point-to-point invisible protected communication. The directional antennas have

higher gain, can be multi-frequency and connected to a multi-functional network. Fly eye micro-radars are inexpensive, can be expendable and will reduce cost of defense.

9074-5, Session 1

Unattended real-time re-establishment of visibility in high dynamic range video and stills

Besma R. Abidi, Phelps2020, Inc. (United States)

We describe an unattended persistent surveillance system that corrects for harsh illumination conditions, where bright sun light creates mixed contrast effects of heavy shadows and highlights. These effects result in high dynamic range scenes, where illuminance can vary from few luxes to a 6 figure value. When using regular monitors and cameras, such wide span of illuminations can only be visualized if the actual range of values is compressed, leading to the creation of saturated and/or dark noisy areas and a loss of information in these areas. Images containing extreme mixed contrast cannot be fully enhanced based on customary image enhancement techniques from a single image, simply because information is not present in the original data. The active intervention in the acquisition process itself is required.

A software package, capable of integrating multiple types of COTS cameras, from miniature to DSLRs is described. Hardware and software are integrated via a novel smart data acquisition algorithm, which communicates to the camera the parameters that would maximize the visibility in the final processed scene. A fusion mechanism is then applied to the smartly acquired data, resulting into an enhanced scene where information in both dark and bright areas is revealed. Multi-threading and parallel processing are exploited to produce automatic real time full motion corrected video. A novel enhancement algorithm was also devised to process data from legacy, non-controllable, cameras, as well as accept and process pre-recorded sequences and stills. The software enhances visible and Infrared data and was successfully applied to night time and dark scenes. A User-friendly Graphical Interface integrates the various functions of the application into an intuitive and easy to use screen window.

The ensuing increase in visibility in surveillance video and intelligence imagery will expand the performances and timely decision making of the human analyst, as well as that of unmanned systems performing automatic data exploitation, such as target detection and identification.

9074-6, Session 1

Improving performance of EMP surge arrester response time, clamping voltage and joules rating by implementation of primary sensor and a delay line

Akbar Rahmani-Nejad, Independent Researcher (Iran, Islamic Republic of)

We designed and developed a new kind of surge arresters in which three above mentioned factors is improved considerably such that to protect systems even at the range to be efficient against high altitude EMP bombs while remaining production cost as low as ordinary MOV arresters. This arrester is comprised of two sections that are separated by two parallel lines both initiating from first section and terminating to the second section, first line has the length of magnitude in the range of micrometers-millimeters and second line has the length of about several centimeters-meters. A small portion of surge current is coupled to the first line which acts as driving line for the main arrester. second part, which is an ordinary arrester and arrests surge current of the main line. By consideration of delay time introduced by length difference of two lines which can be about a few nanoseconds to a fraction of a microsecond that is enough time for the main arrester to arrest surge current. By coupling of a small portion of surge current to driving line of arrester most of current passes through the main line. The length-difference of two lines makes the main arrester to act hundreds of nanosecond in advance to reaching the surge pulse. Due to moving energy pulse in main line almost close to light speed (96% to 97% of light speed), it is possible to use an optical fiber to drive the main arrester.

9074-7, Session 1

What are the advantages and disadvantages of centralized control of air power at the operational level?

Uğur Arisoy, Turkish Air War College (Turkey)

"The successes of the air campaign in the gulf rested almost as much on organizational innovations as on technology. To speak of a revolution in warfare as a purely technological affair is to miss half the significance of the war... The centralized control of air power made for a much more coherent campaign than would otherwise have occurred."

Eliot Cohen in Foreign Affairs

SUMMARY: People do not want to see and hear the war. In today's world, if war is inevitable, the use of Air Power is seen as the preferable means to conduct operations instead of financially burdensome land battles those are more likely to cause heavy loss of life.

The use of Air Power has gained importance in NATO operations in the Post-Cold War era. For example, Air Power has been undertaken a decisive role from beginning to the end of the operation in Libya, 2011.

From this point of view, the most important issue to consider is how to direct the Air Power more effectively at the Operational Level. In this context, NATO's Core JFAC (Joint Force Air Command) was established in 2012. Joint Air Power is directed from a single center at the Operational Level by the means of JFAC. The most important feature of JFAC is high readiness capability for any possible task. JFAC structure requires trained and specialized personnel.

JFAC aproach provides complex planning progress of Air Power to be overcome faster in a single center. An Air Power with a large number of aircraft, long range missiles of cutting-edge technology may have difficulties in achieving results unless directed effectively. Automation systems are needed for planning process in order to adapt quickly to the changing operational environment and for the proper allocation of resources to the targets.

Directing Air Campaign from a single center similar to JFAC-like structure is helping to attain desired objectives at the end of the operation. Beyond the classical approach, it is possible to blend more functions in coordination within an operation center like JFAC. For this purpose, opportunities in technology should be utilized more and automation systems should be developed. Because there are no coincidences in the use of Air Power.

In this article, Directing Air Power more effectively at the Operational Level has been studied in the framework of several scenarios based on SWOT analysis technique. "Directing Air Power at the Operational Level from a single center similar to JFAC-like structure" is compared with "Directing Air Power at the Operational Level from two centers similar to ACC (Air Component Command) + CAOC (Combined Air Operations Center) structure"

As the result of the study, "Directing Air Power at the Operational Level from a single center similar to JFAC-like structure" although having some disadvantages proved to be more effective than the other structure.

The study examined directing Air Power at the Operational Level. Developments at the Political, Strategic and Tactical Levels have been ignored.

9074-8, Session 1

Analysis of a developed analog trilateration system of impulsive sounds

Juan M. López R., Jose I. Marulanda, Univ. EAFIT (Colombia)

A characterization study is made from a trilateration system for impulsive sounds, in which theoretical analysis are compared with experimental results. This system uses an analog trilateration method, avoiding to implement high frequency ADC conversion elements. It also presents the optimization of the chosen array of microphones, thus allowing for a better trilateration algorithm behavior.

9074-9, Session 2

Technology of uncooled fast polycrystalline PbSe focal plane arrays in systems for muzzle flash detection

Mariusz Kastek, Tadeusz Piatkowski, Henryk Polakowski, Jaroslaw Barela, Krzysztof Firmanty, Piotr Trzaskawka, Military Univ. of Technology (Poland); German Vergara, Rodrigo Linares Herrero, Raul Gutierrez Alvarez, Carlos Fernandez-Montojo, Maria Teresa Montojo Supervielle, New Infrared Technologies, S.L. (Spain)

The paper presents some aspects of muzzle flash detection using low resolution polycrystalline PbSe 32?32 and 80?80 detectors FPA operating at room temperature (uncooled performance). These sensors, which detect in MWIR (3 - 5 microns region) and are manufactured using proprietary technology from New Infrared Technologies (VPD PbSe – Vapor Phase Deposition of polycrystalline PbSe), can be applied to muzzle flash detection. The system based in the uncooled 80x80 staring FPA monolithically integrated with the CMOS readout circuitry has allowed image recording with frame rates over 2000 Hz (true snapshot acquisition), whereas the lower density, uncooled 32?32 FPA is suitable for being used in low cost infrared imagers sensitive in the MWIR band with frame rates above 1000 Hz.

The FPA detector, read-out electronics and processing electronics (allows the implementation of some algorithms for muzzle flash detection) of both systems are presented. The systems have been tested at field test ground. Results of detection range measurement with two types of optical systems (wide and narrow field of view) have been shown. The theoretical analysis of possibility detection of muzzle flash and initial results of testing of some algorithms for muzzle flash detection have been presented too.

9074-10, Session 2

Gunshot identification system by integration of open source consumer electronics

Juan M. López R., Jose I. Marulanda, Univ. EAFIT (Colombia)

This work presents a prototype of low-cost gunshots identification system that uses consumer electronics in order to ensure the existence of gunshots and then classify it according to a previously established database. The implementation of this tool in the urban areas is to set records that support the forensics, hence improving law enforcement also on developing countries. An analysis of its effectiveness is presented in comparison with theoretical results obtained with numerical simulations.

9074-11, Session 2

Spray-on antisoiling coatings that exhibit high-transparency and mechanical durability

Daniel Schaeffer, Oak Ridge National Lab. (United States)

A superhydrophobic (SH) surface has many characteristics, one of which is its self-cleaning, anti-soiling functionality, that are desirable across various industries. A transparent, self-cleaning surface utilizes the right combination of surface chemistry and roughness that force water droplets to form high water contact angles (CA). This in turn allows droplets to easily roll off and pick up dirt and debris across the surface. In theory this is simple but in practice this can be very difficult as superhydrophobicity and optical transparency are competitive. We have developed a simple, spray-on coating based on functionalized SiO2 nanoparticles that can easily be applied to surfaces whose application requires high transparency including, but not limited to, optical sensors, photovoltaics, sights, and lenses. In addition, these coatings exhibit practical mechanical and environmental durability that allow prolonged use of the coatings in harsh environments.

9074-12, Session 2

Long-range optical projectile tracking

Slobodan Rajic, Oak Ridge National Lab. (United States)

The small arms community has recently seen the introduction of various laser, fiber-optic, and micro-electro-mechanical-system (MEMS) based shooting aids aimed at improving performance. Various commercial sensor approaches exist for measuring variables such as air temperature, weapon inclination angles, target range, etc. There is no question that the presently available sensor portfolio can substantially improve first round hit probability, however, all parameters affecting the projectile flight dynamics, are seldom all quantifiable in advance of the first shot. Thus knowing precisely where a round impacts can be invaluable information to an operator or a mini-fire control computer. The true exterior ballistic information can effectively be used to calculate a new aim point. We have both theoretical and range data to effectively describe our approach.

9074-13, Session 2

Low-cost localization system of impulsive sounds for urban environments

Juan M. López R., Jose I. Marulanda, Univ. EAFIT (Colombia)

A low-cost acoustic localization system is presented, in which a video camera is directed towards the source of impulsive sounds like such as a gunshots. An analog filter is implemented at the first stage, in order to reduce the range of frequencies to analyze, hence narrowing and improving the localization of gunshots. The system is known for the integration of open source consumer electronics and processing devices, which makes large-scale deployment possible even in developing countries. Furthermore, results are also obtained with a prototype that shows a high percentage of successes.

9074-14, Session 3

Cyber threat detection and analysis mechanism

Alexander Milovanov, Leonid Bukshpun, Ranjit D. Pradhan, Physical Optics Corp. (United States)

A new non-signature-based dynamic mechanism has been developed to provide the detection of advanced persistent cyber threats with improved true positive (TP) and false positive (FP) rates acceptable for operational deployment. This mechanism integrates rule-based intrusion detection approach with policy-based intrusion detection and violation weighting approaches. This combination of three approaches allows non-signature detection of currently undetectable new generation cyber threats, such as stealth network reconnaissance, highly distributed and coordinated attacks, low frequency attacks, etc., with deployable TP and FP rates. The presented mechanism can be incorporated into wireless or wired networks that require protection against known and the new generation of cyber attacks.

9074-15, Session 3

Securing wireless networks: distributed network intrusion detection

David Tahmoush, U.S. Army Research Lab. (United States)

A distributable implementation of a network intrusion detection system is very useful for securing wireless networks that have multiple points of entry. We report on a distributable system that operates on top of an existing intrusion detection system (IDS) and uses it as an oracle. The system builds a faster, less resource intensive normalcy classifier as a front-end to a traditional network IDS. This system is more highly scalable and distributable than the signature-based IDS it is based upon. The new design allows distributed updates and retraining of the normalcy classifier to stay up-to-date with current threats, but operates as a distributable front-end for a traditional network IDS.

9074-16, Session 4

A survey on electromagnetic interferences on aircraft avionics systems and a GSM on board system overview

Peppino Fazio, Natale Vinto, Mauro Tropea, Univ. della Calabria (Italy); Miroslav Voznak, V?B-Technical Univ. of Ostrava (Czech Republic)

Recent years have been characterized by an increase in the air traffic. More attention over micro-economic and macro-economic indexes would be strategic to gather and enhance the safety of a flight and customer needing, for communicating by wireless handhelds on-board aircrafts. Thus, European Telecommunications Standards Institute (ETSI) proposed a GSM On Board (GSMOBA) system as a possible solution, allowing mobile terminals to communicate through GSM system on aircraft, avoiding electromagnetic interferences with radio components aboard. The main issues are directly related with interferences that could spring-out when mobile terminals attempt to connect to ground BTS, from the airplane. This kind of system is able to resolve the problem in terms of conformance of Effective Isotropic Radiated Power (EIRP) limits, defined outside the aircraft, by using an On board BTS (OBTS) and modeling the relevant key RF parameters on the air.

The main purpose of this work is to illustrate the state-of-the-art of literature and previous studies about the problem, giving also a good detail of technical and normative references.

9074-17, Session 4

Term selection for an induction motor via nonlinear Lasso

Mohammad Rasouli, Penn State Erie, The Behrend College (United States)

Modeling of the induction motor has been studied extensively due to its increasing application in various areas such as drives, wind turbines, and dynamic component of load models. In this paper, a commonly used third-order model of an induction motor with eight parameters is analyzed in order to classify the model parameters based on their degree of significance in the model behavior. Using the results of this classification, only the significant parameters of an induction motor need to be estimated from the measurements. The remainder of the parameters can be replaced by their typical values, which results in an optimization problem with a reduced dimension. The reduced parameter model needs less computation time and thus is better suited for real-time applications. The significance of this approach is greater when many induction motors or dynamic inductive loads in the system need to be identified.

A nonlinear Least absolute shrinkage and selection operator (Lasso) term selection method is employed for this study. The Lasso method minimizes the sum of squared errors, with a constraint on the L1 norm of the parameter vector, which is used to push some parameters to zero. The main idea involves incorporating the Lasso constraint in an iterative solution approach such as Gauss-Newton algorithm. This method reduces the variance of the parameter estimates, and simplifies the interpretation of the model.

To evaluate the performance of the proposed algorithm, the parameters of an induction motor are estimated. Estimation is performed both for simulated and experimental data.

The results of the proposed approach are compared to those of a method based on sensitivity analysis.

9074-18, Session 4

A data-delivery system using sensor technology and wireless devices for port security

Manuel R. Saldaña, Vidya B. Manian, Javier R. Rivera, Univ. de Puerto Rico Mayagüez (United States)

Sensor technologies such as infrared sensors and hyperspectral imaging, video camera surveillance are proven to be viable in port security. Drawing from sources such as infrared sensor data, digital camera images and processed hyperspectral images, this article explores the implementation of a real-time data delivery system. In an effort to improve the manner in which anomaly detection data is delivered to interested parties in port security, this system explores how a client-server architecture can provide protected access to data, reports, and device status. Sensor data and hyperspectral image data will be kept in a monitored directory, where the system will link it to existing users in the database. Since this system will render processed hyperspectral images that are dynamically added to the server- which often occupy a large amount of space - the resolution of these images is trimmed down to around 1024X768 pixels. Changes that occur in any image or data modification that originates from any sensor will trigger a message to all users that have a relation with the aforementioned. These messages will be sent to the corresponding applications using Google Cloud Messaging for Android, the mobile platform in which this system is being tested. Moreover, this paper presents the complete architecture for data reception from the sensors, processing, storage and discusses how users of this system such as port security personnel can use handheld devices to receive notifications if their designated sensors have detected anomalies and/or have remote access to results from processed hyperspectral imagery relevant to their assigned posts.

9074-19, Session 4

Smart army helmet: A glitch in what soldier helmets can become in the near future by integrating present technologies

Gilberto Osorio, Alejandro Mejía, J. Alejandro Betancur, Univ. EAFIT (Colombia)

Considering the advance stages of technologies like Head-Up Display systems, sensors and intercommunications, in industries like Automobile and Aerospace, just to mention a few; being defense an security where the best improvements had been made technology wise, the need for a low cost alternative keeps growing, and so in this work, it is planned to show the early design stages of an intelligent army helmet that combines this three composite systems in a light shell in order to provide soldiers with information that can give them strategic advantages over the field of combat and most important safe their lives if possible, all of this focusing in low cost production since early stages of design.

9074-20, Session 4

Data storage management in a distributed database with deterministic limited communications windows between data storage nodes

Jeremy Straub, The Univ. of North Dakota (United States)

An orbital service model has been proposed which proposes to distribute tasks between a collection of spacecraft with heterogeneous or additive capabilities. It allows data to be collected, stored and used on different nodes comprising an ad-hoc system where provider craft supply services to consumer craft. Ad-hoc networks and provider-consumer relationships are commonly used in various applications on Earth. The deterministic movement of spacecraft, however, allows the ad-hoc network and service providing model to operate in a different way than would be typical in most terrestrial ad-hoc networks. While long periods of no direct node-to-node connectivity may exist, the periods of connectivity are pre-known based on orbital parameters. Additionally, paths for indirect connectivity can be identified and evaluated for cost effectiveness.

Using the orbital service model, missions can deploy the specialized equipment required to meet unique mission characteristics and utilize a common set of infrastructure spacecraft for many other aspects of mission performance. These infrastructure spacecraft may provide power, computational capabilities, sensing capabilities, communications between spacecraft or between a spacecraft and ground-based operators or other capabilities.

While various ad hoc communications techniques have been previously proposed, they fail to take advantage of the (a) high reliability and (b) deterministic movement characteristics of orbital craft. A method for traffic routing that considered these unique characteristics was proposed. This paper considers how to manage data in an orbital environment. Specifically, it considers where data should be stored and when and how it should be moved or copied to maximize system performance. A data management approach for an orbital computing ad-hoc system is proposed. Algorithms for determining where data should be stored (identification of most useful point of storage, whether multiple copies are justified) and how movement should be affected (transfer scheduling, replication, etc.) are presented and evaluated.

9074-21, Session 5

Bayesian truthing and experimental validation in homeland security and defense

Tomasz P. Jannson, Thomas C. Forrester, Andrew A. Kostrzewski, Wenjian Wang, Physical Optics Corp. (United States)

A broad variety of C3I technologies require some experimental validation (or truthing, using radar terms), in order to validate system performance by using some general objective metrics. The subject of this paper is to show that such general metrics do exist, called by us Bayesian Truthing. In contrast to classical statistical inference, Bayesian Inference is based on conditional probabilities, in general, and on inverse conditional probabilities, in particular, the latter, including such a basic Figure of Merit as Positive Predictive Value (PPV). The PPV is high only when the probability of target priors is higher than the probability of false positives. Therefore, by regulating the population of priors, we can obtain higher or lower PPV values. This is the essence of Bayesian Truthing, which is the basic subject of this paper. The Bayesian Truthing metrics include: sampling space; population of anomalous events, called targets, or signals, embedded in no-targets, false targets, or noise; and, two binary target readouts: alarm or no alarm. The binary Bayesian statistics include four probabilities: two absolute ones and two conditional (direct) ones. By using these simple binary statistics, we can analyze, classify, and evaluate a broad variety of events including: natural disasters, terrorism-related, GIS-related, law enforcement-related, and other C3I events.

In this paper, we discuss the Bayesian Truthing key performance parameters such as probabilities of detection, false positives, false alarms, false negatives, and PPV. Two basic examples are analyzed: terrorism-related events such as terrorism-related networks and Homeland Security related ones.

9074-22, Session 5

Systems integration for an automated checked-baggage inspection system augmented with robots

Taskin Padir, Matthew P. DeDonato, Velin Dimitrov, Worcester Polytechnic Institute (United States)

We posit that despite the significant automation currently employed by the TSA in the Checked Baggage Inspection Systems (CBIS), the addition of innovative robotic technologies in the baggage screening process can significantly reduce the labor-intensive tasks required to manually inspect some bags. Technologies enabling robots to work in close collaboration with humans can address issues in implementing Electronic Baggage Screening Program (EBSP) strategic plan goals. For example, the labor-intensive explosives trace detection (ETD), where a piece of fabric is swabbed across a suspicious bag and placed inside the trace detection machine, can be accomplished with a robot working in collaboration with a human supervisor.

Baxter, developed by Rethink Robotics, enables humans to intuitively interact with robots in close proximity.

Because one of Baxter's target markets is production floors, the robot is designed with work on a conveyor line in mind. Baxter is able to: (1) work safely alongside people, without the need for protective cages; (2) operate collaboratively through a unique, user-friendly UI; (3) be trained manually by line workers, with no programming required; and (4) respond adaptively to changes in its environment.

The automated testbed presented here is comprised of a Baxter research robot for luggage and object manipulation, and a down-looking overhead RGB-D sensor for inspection and detection. By looking at the TSA prohibited items list, one item in particular is relatively common and likely to be left in bags accidentally: the lighter. Lighters pose a risk to aircraft because they are pressurized, and if the fuel disperses as a mist in the cargo hold, due to failure of the pressure vessel, it could cause a serious fire. In addition, due to their generally small physical size, they can be difficult to detect reliably.

The aim of this case study is to create a software framework to demonstrate robotics enabled bag inspection.

The general structure of the software architecture is described as follows. We use the point cloud library (PCL) to implement plane segmentation, allowing us to remove the tabletop and other extra surfaces from the image data. We then create a masked image focused on the detection area. The image data is then processed using OpenCV's template matching algorithm which has been trained apriori on synthetically generated distorted images of a lighter. When a lighter is detected, its 3D position with respect to the sensor is calculated. This is translated into robot-centric coordinates through ROS's TF tool. The path controller generates waypoints to the pickup of the lighter and this information is forwarded into the MoveIt tool which handles motion planning using OMPL. Finally, the generated trajectory is sent to Baxter through the API and Baxter picks up the lighter. The same process using MoveIt is then repeated to place the placard in the bag. Overall, the paper will demonstrate the effectiveness of the developed software architecture in a proof of concept system showing how Baxter or a similar robot could be used in a security inspection scenario.

9074-23, Session 5

Decision generation tools and Bayesian inference

Tomasz P. Jannson, Wenjian Wang, Thomas C. Forrester, Andrew A. Kostrzewski, Christian Veeris, Thomasz Nielsen, Physical Optics Corp. (United States)

Digital Decision Generation (DDG) tools are important software sub-systems of Command and Control Systems and technologies. In this paper, we present a special type of the DDGs based on Bayesian Inference, in general, and on the Bayesian Truthing Theorem (and Bayesian Paradox), in particular. In this paper, we discuss two important applications related to diverse (hostile) networks, namely, terrorism-related networks and organized crime ones. The basic aim of this paper is to show that so-called Bayesian Binary Sensors can operate in cyberspace, in the form of structured cyber-clouds (or databases) reduced here to professional clouds (or, pro-clouds). The proposed DDG architecture is in the form of a chain structure enhanced by cybercloud coherency. This DDG chain structure consists of (about) twenty modules, organized around two main software engines. The intra-cloud engine is in the form of a module set with Bayesian Binary Sensors that detect anomalous behavior. As a result of this network member search, the yellow alarm is produced. Then, as a result of cybercloud coherency and correlation between two DDG engines, a red alarm is produced.

In this paper, the critical DDG components such as Network Synthesizer Systems (NSSs), graphitis, and IED social networks are discussed.

9074-25, Session 5

Comprehensive approach

Oğuz Sayin, Bilal Seymen, Münir Gedikli, Turkish Air War College (Turkey)

The new battlefield, which has been changed by the technological developments, forced countries and organizations to change their concepts. Especially the asymmetric war as a new emerging concept and parallel to this concept 9/11 attack caused a paradigm shift and the nature of the war which had been kept for centuries started to change. After World War II, conventional war left its place to new concepts, which world have not ever seen before like regional conflicts, crisis management and peace support operations. In addition to that, by the technological capabilities operations started to be watched live by the advanced media devices. There are many technological weapons used in operation area such as platforms, munitions, electronic and communication systems and these are all indispensable for us but they are also very expensive and they all increase the cost of war fairly. Considering all these things, in order to decrease the cost of war and prevent the loss and meet the new requirements that come by the paradigm shift, new approaches have arisen.

This study analyzes the Comprehensive Approach concept which has been implemented recently through these specified improvements. We have made a scientific definition of this really new approach, and mentioned the comprehensive approach applications in recent operations. We have discussed Turkey's comprehensive approach applications before even the idea of comprehensive approach such as cooperating with civil institutions and foundations and meeting the needs of the people in the areas of operations. As a result the study emphasizes the importance of this new approach which has not been fully integrated to the structure of armed forces and presents the required conditions for a sound integration.

9074-26, Session 5

Modern air and space power and political goals at war

Gungor Ozer, Turkish Air Force (Turkey)

Modern Air/Space power in today's modern World is increasingly becoming a political tool. Speed, global range, stealth, flexibility, precision, lethality, global/theater situational awareness, and strategic perspective are the most obvious features and advantages of Air/Space power.

In this article Air/Space power as a political tool will be discussed. The primary purpose of this study is to search how Air/Space power can provide contributions to security of a nation and determine if it may reach the political goals at war. Key variables that affect whether Air/Space power can succeed as a political tool will be examined by analysing the limits and superiority of Air/Space power throughout war history.

General thinking on whether Air&Space power can achieve political goals may not help to come to a conclusion since the criteria may vary from one country to another. Therefore, case studies (not only the historical experimentations from the past but also the new scenarios) are examined by making use of the limits & advantages of Air/Space power through SWOT Analysis. The scenarios are compared by Spider Web Analysis Method.

Evidence resulting from the comparative analysis of the case studies supports the conclusion that it is difficult to declare that Air/Space power is sufficient to win the political goals by itself. However it may reach the political aims partially by itself depending upon the cases. But it can firmly be declared that Air/Space power alone can persuade states to alter their behavior(s) in war and is a deterrent tool in peace time.

Thursday 8 –8 May 2014

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9075-1, Session 1

Video understanding *(Keynote Presentation)*

Larry S. Davis, Univ. of Maryland, College Park (United States)

More than two years ago Google announced that the video upload rate to its sharing site, Youtube, was 60 hours of video every minute. By now, the upload rate is certainly much higher. Searching for videos on Youtube is supported through the text that accompanies the video, user comments, etc., but not on the visual or audio content of the video. This talk will cover recent research at the University of Maryland on methods for analyzing the visual content of video to support video retrieval based on natural language queries to video databases. In the jargon of computer vision research, this requires developing so-called zero shot learning algorithms for video classes. That is, users do not provide video search algorithms with examples of videos of interest, just descriptions of the class of interest. Zero shot learning is really a bootstrapping method for obtaining a small set of positive sample from a database so that conventional learning algorithms can be applied to build more powerful recognition models. I will first describe an approach to video classification based on what we call clauselets – small temporal conjunctions of localized activities that are discriminative with respect to classes. Clauselets require extensive training, but a simplification of the model allows us to learn them using novel zero shot techniques. I will present experimental results on the TRECVID MED13 EKO dataset.

9075-2, Session 2

Finger image quality based on singular point localization

Jinghua Wang, Technical Univ. of Denmark (Denmark); Martin A. Olsen, Ctr. for Advanced Security Research Darmstadt (Germany); Christoph Busch, Gjøvik Univ. College (Norway)

Singular point is an important global feature of fingerprints so that singular point localization is a crucial step in biometric recognition. Moreover the presence and position of the core point in a captured fingerprint sample can reflect whether the finger is placed properly on the sensor. Therefore, the displacement given by detected core points is investigated. We propose pattern-based filters to eliminate the false detection given by state of the art approaches. The experimental results show remarkable improvement using different databases. Based on the improved singular point localization algorithm, we explored and analyzed the importance of singular points on biometric systems accuracy. The experiment is based on large scale databases and conducted by relating the measured quality of a fingerprint sample, given by the positions of core points, to the biometric performance. The experimental results show the positions of core points do have influence on the comparison algorithms, but are not as relevant as other benchmarked quality metrics.

9075-3, Session 2

On the fly finger knuckle print authentication

Narishige Abe, Takashi Shinzaki, Fujitsu Labs., Ltd. (Japan)

Finger knuckle print authentication has been researched not only as a supplemental authentication modality to fingerprinting and facial recognition, among other things, but also as a method for logging into a PC or entering a building. However, in previous works, some specific devices were necessary to capture a finger knuckle print and users had to keep their fingers perfectly still in order to capture their finger knuckle.

In this paper, we propose a new on the fly finger knuckle print authentication system using a general web camera. In our proposed authentication system, users can input their finger knuckle print without needing their hand to remain motionless during image capture. We also evaluated the performance of the proposed system, achieving an EER of 2% under best conditions.

To be more specific, we propose a new segmentation technique for finger knuckle prints from a movie by using Gabor feature. In addition, we look into a quality measurement for finger knuckle print based on GLCM analysis. We also evaluated the EER of the proposed system, then we could achieve EER is 2% at the best condition.

9075-4, Session 2

Interpretation of fingerprint image quality features extracted by self-organizing maps

Ivan Danov, Technical Univ. of Denmark (Denmark) and Ctr. for Advanced Security Research Darmstadt (Germany); Martin A. Olsen, Ctr. for Advanced Security Research Darmstadt (Germany); Christoph Busch, Gjøvik Univ. College (Norway)

Accurate prediction of fingerprint quality is of significant importance to any fingerprint-based biometric system. Ensuring high quality samples for both probe and reference can improve substantially the system's performance by lowering false non-matches, thus allowing finer adjustment of the decision threshold of the biometric system. Furthermore, the increasing usage of biometrics in mobile contexts demands development of lightweight methods for operational environment. A novel two-tier computationally efficient approach was recently proposed based on modeling block-wise fingerprint image data using Self-Organizing Map (SOM) to extract specific ridge pattern features, which are then used as an input to a Random Forests (RF) trained to predict the quality score of a propagated sample. This paper conducts an investigative comparative analysis on a publicly available dataset for the improvement of the two-tier approach by proposing additionally three feature interpretation methods, based respectively on SOM, Generative Topographic Mapping (GTM) and Random Forests. The analysis shows that two of the newly proposed methods produce promising results on the given dataset.

9075-5, Session 3

Multimodal biometrics system based on face profile and ear

Iman S. Youssef, Cairo Univ. (Egypt); Ayman A. Abaza, West Virginia High Technology Consortium Foundation (United States) and Cairo Univ. (Egypt); Mohamed E. Rasmy, Ahmed M. Badawi, Cairo Univ. (Egypt)

Face recognition from side profile view, has recently received significant attention in the literature. Even though current face recognition systems have reached a certain level of maturity at angles up to 30 degrees, their success is still limited with side profile angles. This paper presents an efficient technique for the fusion of face profile and ear biometrics. We propose to use Block-based Local Binary Pattern (LBP) to generate the features for recognition from face profile and ear images. These feature distributions are then fused at the score level using weighted sum rule.

Experimental results show that the proposed system can achieve about (97.98%) recognition performance, compared to unimodal biometrics of face profile (96.76%), and unimodal biometrics of ear (96.95%). Detailed comparisons with other multimodal systems used in the literature, like

Principal Component Analysis (PCA), Full-space Linear Discriminant Analysis (FSLDA) and Kernel Fisher discriminant analysis (KFDA), are presented.

9075-6, Session 3

3D face recognition based on the hierarchical score-level fusion classifiers

?t?pán Mrá?ek, Jan Vána, Karolína Lanka?ová, Martin Drahansk?, Michal Dole?el, Brno Univ. of Technology (Czech Republic)

This paper describes the 3D face recognition algorithm that is based on the cascade of score-level fusion classifiers. In a simple (unimodal) biometric pipeline, the feature vector is extracted from the input data and subsequently compared with the template stored in the database. Our approach is the involvement of several feature extraction algorithms. We use 6 different image representations of the input 3D face data (range image, Gaussian curvature, mean curvature, shape index, eigencurvature, and texture). Moreover, we are using Gabor and Gauss-Laguerre filter banks applied on the input image data that yield to 12 resulting feature vectors. Each representation is compared with corresponding counterpart from the biometric database. We also add the recognition based on the iso-geodesic curves. The final score-level fusion is performed on 13 comparison scores using the Support Vector Machine (SVM) classifier. Additionally to the plain score-level fusion, the hill-climbing selection of fused units is added: at initial state, only the best unit providing the lowest EER is selected. In every iteration, the unit that lowers EER the most is added. We have evaluated our results on the FRGC database. The achieved EER is 1.1% and verification rate at FAR = 0.1% is 93%.

9075-7, Session 3

A statistical investigation into the stability of iris recognition in diverse population sets

John Howard, Delores M. Etter, Southern Methodist Univ. (United States)

Iris recognition is increasingly being deployed on population wide scales for important applications such as border security, social service administration, criminal identification and general population management. The error rates for this incredibly accurate form of biometric identification are established using well known, laboratory quality datasets. However, it is has long been established in biometric theory that not all individuals have the same likelihood of being correctly serviced by a biometric system. Typically, techniques for identifying clients that are likely to experience a false non-match or a false match error are carried out on a per-subject basis. This research makes the novel hypothesis that certain ethnical denominations are more or less likely to experience a biometric error. Through established statistical techniques, we demonstrate this hypothesis to be true and document the very notable effect that the ethnicity of the client has on iris similarity scores. Understanding the expected impact of ethnical diversity on iris recognition accuracy is crucial to the future success of this technology as it is deployed in areas where the target population consists of clientele from a range of geographic backgrounds, such as border crossings and immigration check points.

9075-8, Session 4

Keynote Presentation *(Keynote Presentation)*

Ross Michaels, National Institute of Standards and Technology (United States)

No Abstract Available

9075-9, Session 5

Template aging in eye movement-driven biometrics

Oleg V. Komogortsev, Corey D. Holland, Alex Karpov, Texas State Univ. (United States)

This paper presents a template aging study of eye movement biometrics, considering three distinct biometric techniques on multiple stimuli and eye tracking systems. Short-to-midterm aging effects are examined over two-weeks, on a high- resolution eye tracking system, and seven-months, on a low-resolution eye tracking system. We find that, in all cases, aging effects are evident as early as two weeks after initial template collection, with an average 28% (±19%) increase in equal error rates and 34% (±12%) reduction in rank-1 identification rates. At seven months, we observe an average 18% (±8%) increase in equal error rates and 44% (±20%) reduction in rank-1 identification rates. The comparative results at two-weeks and seven-months suggests that there is little difference in aging effects between the two intervals; however, whether the rate of decay increases more drastically in the long-term remains to be seen.

9075-10, Session 5

Human thermal modeling to augment MWIR image analysis in surveillance applications

Renee L. Woodyard, Julie A. Skipper, Wright State Univ. (United States)

The interpretation of thermal imagery can be augmented with information derived from human thermal modeling to better infer human activity during, or prior to, data capture. This additional insight into human activity could prove useful in security and surveillance applications. We have implemented Tanabe's 65 NM thermocomfort model to predict skin surface temperature under a wide variety of environmental, activity and body parameters. Here, humans are modeled as sixteen segments (head, chest, upper leg, etc.), wherein spherical geometry is assumed for the head and cylindrical geometry is assumed for all other segments. Each segment is comprised of four layers: core, muscle, fat, and skin. Clothing is modeled as an additional layer (or layers) of resistance. Users supply input parameters via our custom MATLAB graphical user interface that includes a robust clothing database based on McCullough's A Database for Determining the Evaporative Resistance of Clothing, and then Tanabe's bioheat equations are solved to predict skin temperatures of each body segment. As an initial step of model validation, we compared our computed thermal resistances with literature values. Our evaporative and dry resistance on a per segment basis agreed with literature values. Model validation will be extended to compare the results of our human subject trials (known body parameters, clothing, environmental factors and activity levels) to model outputs. Agreement would further substantiate the propagation of model- predicted skin temperatures through the thermal imager's transfer function to predict human heat signatures in thermal imagery.

9075-11, Session 6

Scrambling faces for privacy protection using background self-similarities

Andrea Melle, Jean-Luc Dugelay, EURECOM (France)

The pervasive adoption of video surveillance systems demands tools for protecting the privacy of the subjects being monitored. Current solutions are either naive or they lack of important characteristics, such as reversibility or visual quality preservation. In this paper, we propose a novel scrambling procedure for protecting privacy sensitive image regions, which encodes the sensitive data in a parametric form, exploiting the visual information in the remaining part of the image. The encoded data is encrypted with a secret key. Partial knowledge of encryption key gives a protected version of the

original image at variable levels of scrambling, while the knowledge of the full key allows decryption to a quality level suitable for subject identification. To evaluate the proposed approach, we apply our scrambling filter to the AT&T face recognition dataset and we measure the resulting quality with an objective metric. Furthermore, we evaluate the robustness of our privacy protection filter to state-of-art face recognition algorithms and, as an additional contribution, we show that our method offers robustness to further JPEG compression of the image prior to decryption.

9075-12, Session 6

Secure fingerprint hashes using subsets of local structures

Tom Effland, Mariel Schneggenburger, Jim Schuler, Univ. at Buffalo (United States); Bingsheng Zhang, National and Kapodistrian Univ. of Athens (Greece) and Univ. at Buffalo (United States); Jesse L. Hartloff, James Dobler, Sergey Tulyakov, Atri Rudra, Venu Govindaraju, Univ. at Buffalo (United States)

n order to fulfill the potential of fingerprint templates as the basis for authentication schemes, one needs to design a hash function for fingerprints that achieves acceptable matching accuracy while at the same time has provable security guarantees especially for parameter regimes that are needed for matching of fingerprints in practice. Existing matching algorithms while achieving impressive matching accuracy have no security guarantees. On the other hand provably secure hash functions have bad matching accuracy and/or have no security guarantees for practical setting of parameters.

In this work we present a secure hash function that has the best known tradeoff between security guarantees and matching accuracy. At a high level, our hash function is simple: we apply an off-the shelf hash function on certain collection of minutia points (in particular, triplet of minutia “triangles”). However, to realize the potential of this scheme we have to overcome certain theoretical and practical hurdles. In addition to the novel idea of combining clustering ideas from matching algorithms with ideas from provable security of hash functions, we also apply an intermediate translation invariant but rotation variant map to the minutia points before applying the hash function. This latter idea helps up tradeoff between matching accuracy and matching efficiency.

9075-13, Session 6

En-face full-field optical coherence tomography for fast and efficient fingerprints acquisition

Claude Boccara, Institut Langevin (France); Eugénie Dalimier, Fabrice Harms, LLTECH SAS (France)

Optical coherence tomography (OCT) has been recently proposed by a number of laboratories as a promising tool for fingerprints acquisitions and for fakes discrimination. Indeed OCT being a non-contact, non-destructive optical method that virtually sections the volume of biological tissues that strongly scatter light it appears obvious to use it for fingerprints. Nevertheless most of the OCT setups have to go through the long acquisition of a full 3D image to isolate an “en-face” image suitable for fingerprint analysis. A few “en-face” OCT approaches have been proposed that use either a complex 2D scanning setup and image processing, or a full-field illumination using a camera and a spatially coherent source that induces crosstalks and degrades the image quality.

We show here that Full Field OCT (FFOCT) using a spatially incoherent source is able to provide “en-face” high quality optical sectioning of the fingers skin. Indeed such approach shows a unique spatial resolution able to reveal a number of morphological details of fingerprints that are not seen with competing OCT setups. In particular the cellular structure of the stratum corneum and the epidermis-dermis interface appear clearly. We describe our high-resolution (1 micrometer, isotropic) setup and show our first design to get a large field of view while keeping a good sectioning ability of about 3 micrometers. We display the results obtained using these two setups for fingerprints examination.

9075-14, Session Posters-Thursday

Exploiting quality and texture-based characteristics to predict age and gender through fingerprint images

Emanuela Marasco, Luca Lugini, Bojan Cukic, West Virginia Univ. (United States)

Age and gender provide ancillary information about an individual, which is not discriminative and permanent enough to differentiate two individuals. However, they can contribute to the evidence provided by primary biometric identifiers such as fingerprints and help to enhance the matching performance in adverse acquisition conditions (e.g., low quality images). We observed that distributions of match scores and quality measures vary based on gender and age. In particular, genuine match scores are higher for males and for subjects of an age below 55; also, fingerprint images of subjects between the age of 36 and 55 have higher average quality than those of older users. We propose a system which infers such soft biometrics directly from the fingerprint image. In existing approaches fingerprints are classified based on gender / age using statistics such as white lines count and ridge count that are manually extracted as proposed by Acree. Recently, a method based on both discrete wavelet transform DWT and singular value decomposition SVD has been proposed for gender and age estimation; the decomposed sub-bands images are four. This method achieves low accuracy for subjects of age 36 and above. Our model exploits image quality-based features such as the ridge strength computed as the energy concentration in the power spectrum considering forty different sub-bands in order to capture more details about small changes in the image; local image texture properties such as those captured by LPQ and LBP descriptors with optimized division of the whole image in sub-regions; and, characteristics related to the extractability of features (e.g., minutiae count, contrast, etc.). The evaluation is carried out on data collected at West Virginia University from 500 users with 4 optical fingerprint devices. By the proposed method, fingerprints are classified accurately for both female and male of age ranging between 18 and 75 years old.

9075-15, Session Posters-Thursday

Robust human facial feature detection on mobile platform for human-robot interaction

Chang-Woo Park, Korea Electronics Technology Institute (Korea, Republic of)

For the vision based human-robot interaction of the mobile service robots, the first step of any human face analysis techniques such as face recognition or facial expression recognition is to detect locations in image where faces are present and to estimate their facial features' locations. Basically, general face detection algorithms of previous researches use the fixed-base camera system. However, in moving platform of the mobile robot, it is hard to reliably detect face and facial features with these algorithms. Main reason is the mobility of robot platform; a mobile robot may move at indoor environment and thus, it makes a difficult situation that detection algorithms have to deal with facial pose variation, dynamic background change, and illumination change. Many researches in finding the eye and mouth regions or locating facial region in an image have been proposed. In general, these facial feature detection methods can be classified into three categories: geometrical-based approach, appearance-based approach, and feature invariant approach. However, geometrical-based approach requires many templates to correctly locate the eyes and brings about a computational burden to handle shape variation globally for pose variations. In a classical example of appearance-based methods, eigenspace representation for individual features, i.e. eyes and mouth was utilized. But, this method was also affected by rotations and illumination variations and required to train many sample images for applicability to these variations. Therefore, for

achieving robust feature detection, both geometrical and appearance-based methods require many templates to accommodate varying pose and lighting conditions. Another approach is feature invariant methods. These algorithms are related to find consistent features that they hold their distinctions even when the pose, viewpoint, or illumination conditions vary. In many researches related to invariant-based method for facial features, two typical invariants are facial color and edge property. However, it has several problems to use color as a feature clue. The color representation is influenced by ambient light and background, and different cameras may produce significantly different color value; the chromatic distribution of pixels in each facial feature can vary from person to person. Also if camera shows low quality of color chrominance, it is difficult to distinguish eye or mouth clearly from each chromatic map. Moreover, if facial area is tiny or the eye (mouth) features in face are small, features can be concealed in facial color region and cannot be found easily. On the other hand, even when facial features are seen to be unclear, detail shape of features can be effectively presented as the form of edge image created by two dimensional differential mask operations. However, these edge maps are created on the bases of frontal face edge figures and also their similarity measures are computed from these frontal normal maps. Therefore, in the case of pose variant or unknown viewpoint facial images, correct detection rate is considerably decreased.

In this paper, in order to overcome such difficult problems, we suggest a new and efficient approach for detecting face and facial features, which is based on local image region and direct pixel-intensity distributions. Compared with the previous approaches such as appearance based method and eigen-face representation, the proposed method use only local image region, which is similar to the component-based approach. Therefore, our method can compensate for pose-change effects by allowing a flexible geometrical relation between local regions. Unlike the previous feature-based methods such as edges, contour and skin-tone color are generally affected by different lighting conditions and complex backgrounds, the proposed method utilizes direct pixel-intensity distributions without extracting any visual features as low level processing; the detection results in feature-level are more reliable under above conditions. For this, we first suggest a new directional template for effective estimation of the locations of major facial features, i.e., two eyes and a mouth. Next, this template is applied to the input image for creating a new edge-like blob map with multiple intensity strengths. This blob map is based on the intensity distributions of neighborhood pixels around facial features' region. For multiple directions, only relative intensity differences are taken into account. Various experiments are carried out using many images, especially appropriate to mobile robot applications; the well-known gray-level face databases and it shows good results in detecting facial features in moderate changes of pose and lighting condition.

9075-16, Session Posters-Thursday

Detection of latent fingerprints by near-infrared spectral imaging

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Spectral imaging technology research is becoming more extensive in the field of examination of material evidence. Near-Infrared spectral imaging technology is an important part of the full spectrum of imaging technology. Due to the limitations of previous devices, most research has focused on technology of the visible light. The study of Near-Infrared spectral imaging technology is much fewer. This paper summarizes the application of the results of Near-Infrared imaging technology in the field of forensic science, explores the common object of latent fingerprints of Near-Infrared spectra characteristic for the research objectives, which shows the potential traces of criminal using the Near-Infrared spectrum imaging method.

This paper finished the experiment contents of the Near-Infrared spectrum imaging method and image acquisition system Near-Infrared spectral imaging technology. The experiment of Near-Infrared spectral imaging method obtains the image set of the Near-Infrared spectrum, and formats a pseudo-color images to show the potential traces successfully by processing the set of spectral images; Near-Infrared spectral imaging technology explores the technology method of obtaining the image set of Near-Infrared spectrometer and image acquisition system, and extensive access to the Near-Infrared spectrum information of latent blood, stamp and smear fingerprints on common objects, and study the characteristics of the Near-Infrared spectrum.

In this paper, the experimental Near-Infrared spectral imaging method for the Near-Infrared spectral imaging technology provides a reference path to practical experience for future experiments. Near-Infrared spectroscopic imaging experiments explores a wide variety of Near-Infrared reflectance spectra of the object material curve and its Near-Infrared spectrum of imaging modalities, can not only gives a reference for choosing Near-Infrared wavelength to show the object surface potential traces of substances, but also gives important data for the Near-Infrared spectrum of imaging technology development.

9075-17, Session Posters-Thursday

Designing low-cost prosthetic arm

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The goal of the project is to build a functional low-cost prosthetic arm that is easily maintained. The focus is on prostheses that attach to the forearm. This design must perform daily life tasks such as picking up, holding and carrying objects while playing and working. To begin the design, a mechanical finger was built with wooden tongue depressors as bone material; rubber bands, string, and drinking straws as muscle material; and masking tape as ligament and tendon material. The length of each joint was set to the golden ratio. Using this method, a basic "hand" was created that could be used to grip objects. The second step was to determine the amount of surface area needed to impart appropriate pressure for gripping objects without causing damaging. This was measured using an olive as a model. The pressure required to puncture the skin of an olive with an object of known surface area was determined. Newton's first law was used to derive the graph of Force vs. Area of the finger tip. Each fingertip should have a surface area of at least 3.67 mm2 to prevent damage to objects encountered in daily life. The significance of the project is to develop an effective low-cost, easily maintained prosthetic arm that could benefit people with disabilities in developing nations or who are living below the poverty line.

9075-18, Session Posters-Thursday

Facial biometrics based on 2D vector geometry

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Biometrics is an automated method of authenticating an individual based on their measurable physiological and behavioural characteristics. The common biometric traits in this characterization process are fingerprint, face, iris, hand geometry, gait, voice, signature and keystrokes. Fingerprint, face and iris traits are widely used in the field of biometric technology. More importantly, government and law enforcement organizations including military, civil aviation and secret service often need to track and authenticate dynamic targets under surveillance. Organizations are also required to ensure that an individual in a room or crowd is the same person who had entered it. As a result, a step in the direction of facial biometrics is regarded as a conclusive solution in this area. This is because they can facilitate the extraction of unique and undeniable physiological and behavioural characteristics without having the target?s (subject) intrusion or knowledge. There are many different methodologies that have been studied for biometric authentication systems, including shape of the facial features, skin color and appearance. Among them, the feature-based method is the most efficient due to its measurability, universality, uniqueness and accuracy. This approach is becoming the foundation of an extensive array

of highly secure identification and personal verification solutions. The most commonly used facial features are the nose, eyes, lips, chin, eyebrows and ears. The performance and robustness of the authentication system are largely dependent on the features localization and extraction process. Furthermore, the feature extraction process can be defined as the process of selecting and extracting relevant and useful information which uniquely identify a subject of interest. The overall processing of the system must also be computationally efficient. However, the human face is a dynamic object with a high degree of variability in its position orientation and expression. On the other hand, noncooperative behaviour of the user and environmental factors including illumination effects also play an unfavourable role in the facial feature extraction process. Consequently, extracted features are contaminated due to the underlying challenges. Therefore, a vital issue of facial biometrics is to develop an efficient algorithm for biometric authentication method in order to overcome the aforementioned challenges. Many facial biometric authentication methods have been studied based on the geometrical features extraction and selection process. In most studies, biometric authentication algorithms have been developed under the assumption that the candidate geometrical features to be extracted in the authentication process are fixed. However, scopes for the accessibility of the same facial geometrical features accept challenges due to facial orientation in the time domain. In addition, even if the facial features can be accessible, their quality is contaminated by facial expression and illumination due to the dynamic properties of the human face and environmental factors, respectively. Some of studies have also been conducted based on variabilities in the features extraction and selection process. But, these variabilities were introduced at the cost of processing time, storage and memory. This paper addresses the predominant deficiency in this regard. Afterward, it system- atically investigates the facial biometric systems under the assumption that facial geometry is influenced by position orientations, facial expressions and illuminations. In the proposed method, a new facial authentication algorithm is being developed to address the underlying challenges due to position orientation, facial expression and illumination. In this method, biometric feature selection, extraction and authentication systems have been processed in 2D geometrical space. Each of the candidate facial features is considered as a collection of geomet- rical coordinates in the Euclidean domain. Euclidean distance between the candidate feature coordinates is estimated and stored as a vector to create the biometric template. Moreover, this template is compared with the stored template to authenticate the legitimacy of the subject of interest. The motivation of this method is its ability to select the biometric features based on their quality and accessibility, and then extract them to create the biometric template. Importantly, the variabilities of feature selection and extraction are processed without sacrificing efficiency in terms of computing time and memory usage. For the experimental evaluation of the proposed method, the facial images of the public “Put Face Database” are used. The performance of the proposed method is evaluated based on correct recognition (CRR), false acceptance (FAR) and false rejection (FRR) rates. FAR of 0.87% at the cost of 5.8% FRR has been achieved by the proposed method. The experimental results demonstrate the superiority of the proposed method in comparison with its counterparts.

9075-21, Session Posters-Thursday

Remote authentication using vaulted fingerprint verification

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We present a novel approach to remotely authenticating a user using a vaulted fingerprint verification (VFV) protocol. We adapt the concept of Vaulted Verification to the fingerprint modality using a minutiae triangle representation.

Triangle-features have been in used in multiple fingerprint algorithms. Triangles are constructed from three fingerprint minutiae, resulting in a feature vector that is translation and rotation invariant. In VFV, the user’s minutiae triangles are arranged into blocks. Each block of triangles is paired with a chaff block. Each real/chaff block is encrypted with a key known only to the users. These encrypted block pairs can be used to generate a challenge by swapping blocks according to a random bit string, and challenging the remote user to reproduce that string.

For identity verification, a user creates a new feature vector from a fingerprint. This feature vector is matched against each block, allowing the user to identify, with high probability, the “real” block in each pair, and subsequently the full bitstring. Triangle matching is imperfect. We improve matching rates by using approximate matching on the feature vectors, grouping several feature vectors together, and correcting errors on the final bit string.

We present data on optimal threshold for approximate matching, accuracy of triangle matching, the distinguishability of a user’s and a chaff triangle, and the accuracy of the vaulted fingerprint verification system.

9075-22, Session Posters-Thursday

Mobile user identity sensing using the motion sensor

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Employing mobile sensor data to recognize user behavioral activities has been well studied in recent years. However, to adopt the data as a biometric modality has rarely been explored. Existing methods either used the data to recognize gait, which is considered as a distinguished identity feature; or segmented a specific kind of motion for user recognition, such as phone picking-up motion. Since the identity and the motion gesture jointly affect motion data, to fix the gesture (walking or phone picking-up) definitively simplify the identity sensing problem. However, it meanwhile introduces the complexity from gesture detection or requirement on a higher sample rate from motion sensor readings, which may draw the battery fast and affect the usability of the phone. In general, it is still under investigation that motion based user authentication in a large scale satisfies the accuracy requirement as a stand-alone biometrics modality. In this paper, we propose a novel approach to use the motion sensor readings for user identity sensing. Instead of decoupling the user identity from a gesture, we reasonably assume users have their own distinguishing phone usage habits and extract the identity from fuzzy activity patterns, represented by a combination of body movements whose signals in chains span in relative low frequency spectrum and hand movements whose signals span in relative high frequency spectrum. Then Bayesian Rules are applied to analyze the dependency of different frequency components in the signals. During testing, a posterior probability of user identity given the observed chains can be computed for authentication. Tested on an accelerometer dataset with 347 users, our approach has demonstrated the promising results.

9075-23, Session Posters-Thursday

Biometric recognition via fixation density maps

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This work introduces and evaluates a novel eye movement-driven biometric approach that employs eye fixation density maps for person identification. The proposed method is inspired from the research that is conducted in the field of low-level visual saliency and it suggests the formation of an analogous conspicuity structure by using directly the fixation samples coming from different subjects during the observation of visual stimuli and the utilization of it as a biometrical template. The suggested feature offers a dynamic representation of the biometric identity, storing rich information regarding the behavioral and physical eye movement characteristics of the individuals. Furthermore, the innate ability of fixation density maps to capture the spatial layout of the eye movements in conjunction with their probabilistic nature makes them a particularly suitable option as an eye movement biometrical trait in cases when free-viewing stimuli is presented. For the comparison of the extracted features two different measures are evaluated, that have been previously employed during similarity assessment of low-level visual saliency maps. The first one is Similarity Score, which is a measure that shows how similar two density

maps are by evaluating their activation coherence at every spatial location. The second measure is Kullback-Leibler divergence, which expresses the overall dissimilarity between two distributions by calculating the relative entropies of their probability density functions (here the fixation density maps). The effectiveness of the proposed approach is evaluated on three datasets containing eye movements in response to stimuli of various types (face images, video sequences and text). The first one (faces images) is a dataset that has been already used in the past for the evaluation of a graph-based technique inspecting eye movement biometrics. The other two (video sequences and text) are originally used in the current work and they were recorded with the use of a high speed eye tracking device (1000 Hz) and with a large pool of 100 subjects. During the evaluation part, an experimental analysis is conducted exploring the influence of the algorithm parameters for the two comparison measures that were tested (Similarity Score and KL-divergence). The obtained results indicate a minimum Equal Error Rate (EER) of 18.3%, revealing the perspectives on the utilization of fixation density maps as a soft biometric cue during identification scenarios in dynamic visual environments.

9076-1, Session 1

Nonlinear sampling for efficient implementation of the projection-slice synthetic discriminant function filter

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The Projection-Slice Synthetic Discriminant Function Filter has been generated using a sparse sampling technique that utilizes the inherent sprsity of the Projection-Slice theorem. The l1-norm has been utilized to optimize the information contents extracted from the representative class objects. In this work, the results of the usual PSDF without the benefit of convex optimization is compared with the results of the PSDF filter after utilization of convex optimization to assess the merits of the utilization of efficient information reconstruction within the construct of the PSDF.

9076-2, Session 1

High-performance electronic image stabilisation for shift and rotation correction

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A new processing concept has been developed that provides high-performance electronic image stabilisation for daylight and infrared cameras. The algorithmic design approach provides an accurate correction of both shift and rotation by means of adaptively sized windows across the sensor's field of view. Additionally, the design allows for movement in the position of the centre of rotation which is important for many different military systems including UAV platforms. Furthermore, underlying (true) platform motion is retained by means of temporal-based filters that can support adaptive learning. The stabilisation algorithm has been implemented using a hybrid firmware and software framework that enables the stabilisation of HD video and infrared cameras at frame-rates of up to 100Hz. The design has been extensively stressed-tested and can achieve a stabilisation accuracy of better than 2 pixels when subjected to a random frame-to-frame movement of ± 70 pixels (averaged over the field).

Within this paper, the design approach will be described and the solution illustrated with results from the development stress-testing programme. The achieved performance is compared directly with that using other approaches that are widely used in security and defence systems. This comparison will include results from both laboratory measurements and field trials. Finally, potential applications are described where the electronic image stabilisation is used as either a stand-alone function (such as direct operator image interpretation) or as part of an integrated processing suite for applications that involve assisted and automated alerting, cueing and recognition systems.

9076-3, Session 1

Identification of spatially corresponding imagery using content-based image retrieval in the context of UAS video exploitation

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For many tasks in the fields of reconnaissance and surveillance it is important to know the spatial location represented by the imagery to be exploited. A task involving the assessment of changes, e.g. the appearance or disappearance of an object of interest at a certain location can typically not be accomplished without spatial location information associated with the imagery. Often, such georeferenced imagery is stored in an archive enabling the user to query for the data with respect to its spatial location to enable the user to effectively find spatially corresponding imagery to be used for change detection tasks.

In the field of exploitation of video taken from unmanned aerial systems (UAS), spatial location data is usually aquired using a GPS receiver together with an INS device providing the sensor orientation both integrated in the UAS. If during a flight valid GPS data becomes unavailable for a period of time, e.g. due to transmission problems, the imagery gathered during that time is not applicable for change detection tasks. Furthermore, GPS and INS inaccuracy together with a potentially poor knowledge of ground elevation can also render location information inapplicable.

In this paper, we present a search method based on the content of the images to find imagery spatially corresponding to given imagery independent from georeference quality. Using methods from content-based image retrieval (CBIR), we build an image database which allows for querying even large imagery archives very efficiently. We further evaluate the benefits of this method in the context of a video exploitation workflow on the basis of its integration into our video archive system.

9076-4, Session 1

Meta-image navigation augmenters for GPS denied mountain navigation of small UAS

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GPS is a critical sensor for Unmanned Aircraft Systems (UASs) due to its accuracy, global coverage and small footprint. However, it is subject to denial due to blockage or interference. When GPS is unavailable, position, velocity and attitude (PVA) performance from other inertial and air data sensors is insufficient to maintain a sustainable PVA solution. This problem is especially true for SWaP challenged UASs. Terrain further aggravates the challenge, because its inherent randomness makes image navigation via conventional correlation/correspondence based approaches highly unreliable, computationally intractable, and usually impossible. In this work of novel we present a real-time monocular image navigation system to address GPS outages for SWaP Challenged UASs; an autonomous synergy of machine-vision and machine-learning for true map aided navigation. Our design uses publicly available, open source geo-referenced radar returns (GRRR) in conjunction with real-time monocular imagery. We obtain GRRR data from NASA SRTM database. Innovating on our previous work addressing a similar problem (Celik et al., "Meta-image navigation augmenters for unmanned aircraft systems (MINA for UAS)", ISR Systems and Applications X, 5/2013), we present a novel strategy for GPS denied UAS navigation which allows flight not only in urban areas, but over challenging terrain with no human-made structures. In GPS denied state we use GRRR data in conjunction with state of the art 3D graphics algorithms to recreate expected camera-appearance of any terrain under current flight conditions, time of day, weather, and season. Rock type and altitude based vegetative state are considered probabilistically. This realistic mountain replica is injected into UAS video signal as if sourced from a physical camera, with all appropriate lens and sensor modeling. We then perform medical arteriogram image-processing with wavelet transforms on both the real and replica terrain to "fingerprint" drainage patterns of any terrain and match to GRRR via spline transforms. Our experimental results indicate robust performance even over most challenging mountain areas, and smooth transition into urban areas due to backwards compatibility with MINA. Since GRRR requires large storage, we also present a new molecular data structure that organizes UAS mission maps as collections

of discrete atoms, linked by aircraft dynamics using OpenStreetMap backbone. This data structure applies spectral graph theory, rigidity matrices, and compressed sensing to geo-registered map systems such as GRRR, OpenStreetMap, and similar, resulting sparse but high quality maps. We illustrate how such a map as itself can be used as a navigational aid to augment the PVA state of the UAS when both GPS and imager are not available.

9076-5, Session 1

Parallax visualization of full motion video using the Pursuer GUI

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Using the Pursuer graphical user interface (GUI), the authors developed a parallax visualization (PV) plug-in toolset for wide area motion imaging (WAMI) data. In addition to PV of WAMI data, the Phase 1 plug-in toolset also featured a limited ability to visualize FMV data. The ability of an electric light table (ELT) toolset that can visualize both WAMI and FMV data is highly advantageous if rapid analysis is desired. This paper reports on the Phase 2 development and addition of a full featured FMV capability to the Pursuer WAMI PV Plug-in.

Pursuer is a Persistent Viewer, graphical user interface that was designed to assimilate WAMI, ground-based sensor data, and narrow-field-of-view (aka FMV) sensor overlays for review in a single composite display. Pursuer contains infrastructure that allows for the creation of Plug-in Module NBM files that introduce new tools and features. One such module is the Parallax Visualization Plug-in toolset, which has been developed for use with Pursuer released versions 2.3.3 to 2.3.8 and future 2.3.10.

PV allows for the exploitation of spatial and temporal differences in image sequences in order to enhance depth, size, and spatial relationships of objects in areas of interest. Any two images in a dataset that contain different angles of view can be visualized in a manner that will render object shapes and ambiguous surface features obvious. PV toolsets can process existing or newly captured sensor data to identify and isolate targets from their surroundings.

PV Plug-in Phase 1 ended 12/31/12, during which a limited FMV capability was added to the WAMI toolset. Subsequent testing of the Plug-in's FMV component proved the capability to be very effective. However, the PV Plug-in FMV capability did not have the same full functionality of the WAMI toolset, only allowing two frames to be manually captured and visualized at one time.

Phase 2 expanded the FMV toolset PV capability to have an additional full feature toolset similar to the WAMI capability. The expansion is:

1. Multi frame capture capability
2. Automatic Frame capture capability
3. Random frame pattern assembly
4. Frame Stabilization
5. Scaling adjustment of frames
6. Frame Rectification

In addition, a rough mensuration capability was added a part of the Phase 2 effort. This feature allows a user to quickly and closely estimate the height of structures and other objects like trees as part of the PV process.

The addition of a full FMV feature set to the PV Plug-in expands Pursuer's ISR capabilities significantly to allow for multiple data inputs. Subsequent testing indicates that the PV Plug-in produces new intelligence from existing WAMI and FMV data. No other ELT software provides this capability.

The primary purpose of geospatial products has always been to visualize operational spaces and activity patterns of all sizes and scales, ranging from global levels to cities and even individual buildings. If a picture is simply the fastest way to communicate spatial information to a customer, then the PV Plug-in succeeds by providing three-dimensional information immediately.

9076-6, Session 2

Effect of video decoder errors on video interpretability

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The advancement in video compression technology can result in more sensitivity to bit errors. Bit errors can propagate causing sustained loss of interpretability. In the worst case, the decoder "freezes" until it can re-synchronize with the stream. When the video errors are better controlled they do not significantly impact interpretability. The video error can be categorized according to their severity. Mitigation of bit error through techniques such as forward error correction, flexible macro blocks, or redundant slices, costs bandwidth which decreased the overall quality of the video by introducing additional blockiness and other compression artifacts which also cause loss of interpretability. Comparison of these two components of video interpretability loss are presented.

9076-7, Session 2

Multiframe image processing with panning cameras and moving subjects

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A common practice in image enhancement algorithms is to aggregate information from a number of temporally or spatially-related frames in order to reconstruct a higher-quality composite output. These multi-frame processing methods are used in techniques such as the computational enhancement of image resolution (known as "super resolution") and the mitigation of atmospheric turbulence in long-range imagery. However, realistic use cases may involve erratic, unpredictable camera behavior or a subject that is prone to movement, which can severely degrade the quality of the results these algorithms produce. In addition, the subject and location during continuous, extended operation may evolve substantially over time, especially in airborne or mobile platforms. In order to deploy multi-frame image enhancement technologies in these operational scenarios, it is critical to handle such circumstances while simultaneously minimizing the need for operator interaction.

In previous research, we have presented such multi-frame algorithms implemented using embedded systems for turbulence mitigation [1] and graphics processing units (GPUs) for super-resolution [2]. Field-testing of these platforms and algorithms has highlighted the need for special techniques, which we developed and presented at SPIE in 2011 [3]. However, these techniques have since proven to be too burdensome for real-time enhancement of HD video, especially in the case of embedded systems.

In this paper we present our latest research into handling arbitrarily panning views and continuously moving subjects in a multi-frame image processing algorithm used for turbulence mitigation. Algorithm efficacy is significantly improved in common scenarios, expanding its operational scope. Unlike our prior research, these methods introduce little computational burden, enabling their use in real-time and low-power solutions, and are appropriate for long observation periods. In addition to our case study focused on imaging through turbulence, we also discuss the generic application of these methods to other multi-frame methods.

We present results of a field study designed to test the efficacy of these techniques under expanded use cases.

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9076-8, Session 2

Marine object detection in UAV full-motion video

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Recent years have seen an increased use of Unmanned Aerial Vehicles (UAV) with video-recording capability for Maritime Domain Awareness (MDA) and other surveillance operations. In order for these efforts to be effective, there is a need to develop automated algorithms to process the full motion videos (FMV) captured by UAVs in an efficient and timely manner to extract meaningful information that can assist human analysts and decision makers. This paper presents a generalizable marine object detection system that is specifically designed to process raw video footage streaming from UAVs in real-time. Our approach does not make any assumptions about the object and/or background characteristics because, in the MDA domain, we encounter varying background and foreground characteristics such as boats, bouys and ships of varying sizes and shapes, wakes, white caps on water, glint from the sun, to name but a few. Our efforts rely on basic signal processing and machine learning approaches to develop a generic object detection system that maintains a high level of performance without making prior assumptions about foreground-background characteristics and does not experience abrupt performance degradation when subjected to variations in lighting, background characteristics, video quality, abrupt changes in video perspective, size, appearance and number of the targets. In the following report, we provide a description of the workflow of the current implementation of marine object detection system with an emphasis on its anomaly detection module. In addition to the overview of our marine object detection system, we also present representative object detection results on some real-world UAV full-motion video data.

9076-9, Session 2

A comparison of moving object detection methods for real-time moving object detection

Aditya Roshan, Yun Zhang, Univ. of New Brunswick (Canada)

Moving object detection has a wide variety of applications from traffic monitoring, site monitoring, automatic theft identification, face detection to military surveillance. Many methods have been developed across the globe for moving object detection but it's very difficult to find one which can work globally in all situations and with different types of videos. The purpose of this paper is to evaluate existing moving object detection methods which can be implemented in software on a desktop or laptop, for real time object detection. There are several moving object detection methods noted in the literature, but few of them are suitable for real time moving object detection. Most of the methods which provide for real time movement are further limited by the number of objects and the scene complexity. This paper evaluates the four most commonly used moving object detection methods as background subtraction technique, Gaussian mixture model, wavelet based and optical flow based methods. The work is based on evaluation of these four moving object detection methods using two (2) different sets of cameras and two (2) different scenes. The moving object detection methods have been implemented using MatLab and results are compared based on completeness of detected objects, noise, light change sensitivity, processing time etc. After comparison, it is observed that optical flow based method took least processing time and successfully detected boundary of moving objects which also implies that it can be implemented for real-time moving object detection.

9076-10, Session 2

Improved frame differencing based moving object detection using feet-step sound

Aditya Roshan, Yun Zhang, Univ. of New Brunswick (Canada)

Moving objects have been detected using various object detection techniques in real-time as well as post-processing. Two categories for moving object detection techniques are frame differencing based and background subtraction based. Further, these techniques are limited by camera scene complexity, lightning conditions, video type etc. Frame differencing based techniques process videos faster compared to background subtraction based techniques and these can be used for real-time moving object detection. Frame differencing based techniques detects only boundary of moving object compared to background subtraction based techniques and there are possibilities of failure for slow moving objects. This can be improved by fusing it with sound data as most video recording cameras comes with a microphone. Some of them comes with mono microphone and some with stereo-microphone. Sounds from human feet steps is recorded with video and fused with frame differencing techniques to detect and track the slow/fast moving object in scene. Stereo microphone data is also used to track the position of object present scene with respect to camera position. An object entering and leaving the scene has been identified using audio data from mono and stereo microphones. The microphones record background noise with other verbal data. This noisy sound data has been filtered out using Fourier transform. Later, presence of multiple objects in scene is also verified from frequency analysis of sound data. The improvement in frame differencing moving object detection technique using audio data allows more accurate real-time moving object detection for slow as well as fast moving objects.

9076-11, Session 3

The trap on the process of modern reconnaissance: reconnaissance gap

Bekir Arapsun, Adem Bora, Turkish Air Force (Turkey)

Military reconnaissance (recce) systems are made of three level as strategic, operational and tactical,related to the mission altitude and divided into two groups as manned and unmanned platforms. The main purpose is to make "image intelligence" of the targets in the operational area to realize the "full-coverage concept." The recce architecture of Turkish Air Force (TurAF) is only consist of tactical level with manned,RF-4E, and Unmanned Aerial Vechiles. In the next year, the wet-based classical system,RF-4E, will be out of service and net-based modern recce system, DB-110 pods entegrated with F-16, will be in service. These pods will mainly be used in high altitude and stand-off distannce and has very limited capacity in low altitude. RF-4E is especially used in low level missions. Briefly, all component of RF-4E will be replaced completely with modern pods. There can be a trap in this transition process.When all targets are under the clouds in the theatre or some of them are located behind the mountains, low level flight is one way to take photos. Otherwise, the recce gaps emerges in the concept of full-coverages due to the low level deficiency of the pods So, the question "Only digital DB-110 is enough for TurAF to cover all targets?" is defined as the main objective of this paper.

In this study, present and future recce architecture of TurAF is analyzed and classical/modern and manned/unmanned structures are compared with fish-bone methods. As a result, stand-off systems should be supported with low level capability for full-coverage.

9076-12, Session 3

Near-space airships against terrorist activities

Ceylan Kesenek, Harp Akademileri Komutanligi (Turkey)

Near-space is a region of atmosphere which is too dense for a satellite to fly also too thin for air breathing vehicles to fly. The Near-space region which is located between 65,000 and 325,000 feet is really underutilized despite its unique potential. Unmanned Lighter Than Air (LTA) systems can be used to exploit the potential of near space. Such a system can supply not only a great deal of information using ISR sensors on board but also serve as a communication relay increasing the range of communications . Airships used in this region can cover a very wide footprint area for surveillance missions. Free of orbital mechanics these near-space assets can continue its mission for long period of time with a persistence of days and months.

These assets can provide persistent intelligence for fight against terrorist activities.

Terrorism is a non-state threat and doesn't have a static hierarchical structure. To fight against such an adversary an overwhelming intelligence activity must be applied. So, Intelligence collection and surveillance missions play a vital role in counter terrorism. Terrorists use asymmetric means of threat that require information superiority . In this study exploitation of near space by LTA airships is analyzed for fight against terrorism. Near-space airships are analyzed according to the operational effectiveness, logistic structure and cost. Advantages and disadvantages of airships are argued in comparison with satellites and airplanes. As a result, by bridging the gap between the air and space, near-space airships are considered to be most important asset of warfighter with its especially operational effectiveness.

9076-13, Session 3

IITET and shadow TT: an innovative approach to training at the point of need

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The Image Intensification and Thermal Equipment Training (IITET) is a joint effort between Night Vision and Electronics Sensors Directorate (NVESD) Modeling and Simulation Division (MSD) and the Army Research Institute (ARI) Fort Benning Research Unit. The IITET effort develops a reusable and extensible training architecture that supports the Army Learning Model and trains Manned-Unmanned Teaming (MUM-T) concepts to Shadow Unmanned Aerial Systems (UAS) payload operators. The training challenge of MUM-T during aviation operations is that UAS payload operators traditionally learn few of the scout-reconnaissance skills and coordination appropriate to MUM-T at the schoolhouse.

The IITET effort leveraged the simulation experience and capabilities at NVESD and ARI's research to develop a novel payload operator training approach consistent with the Army Learning Model. Based on the training and system requirements, the team researched and identified candidate capabilities in several distinct technology areas. The training capability will support a variety of training missions as well as a full campaign. Data from these missions will be captured in a fully integrated AAR capability, which will provide objective feedback to the user in near-real-time. IITET will be delivered via a combination of browser and video streaming technologies, eliminating the requirement for a client download and reducing user computer system requirements. The result is a novel UAS Payload Operator training capability nested within an architecture capable of supporting a wide variety of training needs for air and ground tactical platforms and sensors and potentially several other areas requiring vignette-based serious games training.

9076-14, Session 4

Line-of-sight pointing and stabilization using gimbaled mirror systems

Satyam Satyarthi, IJK Controls LLC (United States)

As the resolution and throughput of optical sensors increase, they require higher line-of-sight slew rates and more precise stabilization. Furthermore, smaller and lighter sensor systems are also preferred because on-vehicle space is always at a premium. Consequently, mirror based line-of-sight control and stabilization systems have become more attractive as they are generally lighter and more compact than other systems. A general strategy for deriving the kinematic equations for mirror based imaging systems is established in this paper. Some of the most common mirror configurations and their basic kinematic equations are also presented. Some practical challenges of mirror stabilization systems are also discussed.

9076-15, Session 4

Line-of-sight kinematics and corrections for fast-steering mirrors used in precision pointing and tracking systems

James M. Hilkert, Univ. of Texas at Dallas (United States) and Alpha-Theta Technologies (United States); Gavin Kanga, Kevin Kinnear, Lockheed Martin Missiles and Fire Control (United States)

The equations describing the line-of-sight (LOS) kinematics of fast-steering mirrors derive entirely from the simple plane-mirror law of reflection. However, when the LOS is pointed about both axes simultaneously, the kinematics are non-linear and axis-coupled and these effects increase as the FSM angular displacement increases. If not properly corrected or accounted for, these inherent effects can contribute to pointing errors. The relevant kinematic equations presented in this paper can be used to assess the magnitude of the errors for a given application and make corrections as necessary. Measurements, using an electronic auto-collimator, were made that are compared against the analytical results for verification of the equations.

9076-16, Session 4

Application of phase matching autofocus in airborne long-range oblique photography camera

Vladimir Petrushevsky, Asaf Guberman, Elbit Systems Electro-Optics El-Op Ltd. (Israel)

The Condor2 long-range oblique photography (LOROP) camera is mounted in an aerodynamically shaped pod carried by a fast jet aircraft. Large aperture, dual-band (EO/MWIR) camera is equipped with TDI focal plane arrays and provides high-resolution imagery of extended areas at long stand-off ranges, at day and night.

The Ritchey-Chretien optical objective is made of highly stable materials. However, in-flight temperature variation still causes some small but significant change of the camera's infinity focus setpoint. Gradual dehumidification of the composite-material structure in dry nitrogen atmosphere inside the pod is an additional factor affecting the focus. To realize the optics' resolution potential, the optimal focus must be constantly maintained. In-flight best focus calibration and temperature-based open-loop focus control give mostly satisfactory performance. To get even better focusing precision, a closed-loop phase-matching (PM) autofocus (AF) method was developed for the camera.

The autofocus makes use of an existing beamsharer prism FPA arrangement, where aperture partition exists inherently in an area of overlap between the adjacent CCD detectors. The defocus is proportional to an image phase shift in the area of overlap. Low-pass filtering of raw defocus estimate reduces random errors related to rapid variation of the scene's spatial content. Closed-loop control loop converges robustly to precise focus position. The algorithm uses the temperature- and range-based focus prediction as an initial guess for the closed-loop PM control.

The AF algorithm achieves excellent results and works robustly in wide range of in-flight imaging conditions.

9076-17, Session 5

Automated multi-INT fusion for tactical reconnaissance

Thomas J. Walls, Michael L. Wilson, U.S. Naval Research Lab. (United States); Jonathan R. Haws, Troy Johnson, Brad Petersen, Space Dynamics Lab. (United States)

The capabilities of tactical intelligence, surveillance, and reconnaissance (ISR) payloads continue to expand from single sensor imagers to integrated

systems of systems architectures. We describe here flight test results of the Sensor Management System (SMS) designed to provide a flexible central coordination component capable of managing multiple collaborative sensor systems onboard an aircraft or unmanned autonomous vehicle (UAV). The SMS architecture is designed to be sensor and data agnostic and provide flexible networked access for both data providers and data consumers. It supports pre-planned and ad-hoc missions, with provisions for on-demand tasking and updates from users connected via data links. The SMS system is STANAG 4575 compliant as a removable memory module (RMM) and can act as a vehicle specific module (VSM) to provide STANAG 4586 compliance (level-3 interoperability) to a non-compliant sensor system. The SMS architecture will be described and results from several flight tests including several sensor combinations and live data link updates will be shown.

9076-18, Session 5

NV-CMOS HD camera for day/night imaging

Thomas L. Vogelsong, John R. Tower, Thomas Sudol, Thomas Senko, David Chodelka, SRI International Sarnoff (United States)

SRI has developed a new day/night camera with low light imaging performance comparable to an image intensifier, while offering the size, weight, ruggedness, and cost advantages enabled by the use of SRI's NV-CMOS HD digital image sensor chip. SRI's new NV-CMOS HD camera captures images over the full range of illumination from bright sunlight to starlight. The digital video output is ideal for image enhancement, sharing with others through networking, or fusion with thermal cameras. The camera provides Camera Link output with HD/WUXGA resolution of 1920 x 1200 pixels operating at 60 Hz. Windowing to smaller sizes enables operation at higher frame rates. High sensitivity is achieved through use of backside illumination, providing high quantum efficiency across the visible and near infrared (NIR) bands (peak QE >90%), as well as low noise (<2e-) readout. Power consumption is minimized in the camera, which operates from a single 5V supply. The NV-CMOS HD camera provides a substantial reduction in weight, power and size, ideal for SWaP-constrained day/night imaging platforms such as UAVs, ground vehicles, fixed mount surveillance, and may be reconfigured for mobile soldier operations such as night vision goggles and weapon sights. The camera comes with an array of lens mounts including C-mount and F-mount. The latest test data from the NV-CMOS HD camera will be presented.

9076-19, Session 5

UAV control for obstacle avoidance in the near-Earth space through use of electric and magnetic field sensors

Harris L. Edge, U.S. Army Research Lab. (United States)

Army Research Laboratory is exploring means to develop autonomous flight capability in the near Earth space. This paper describes a component of that research which is to provide autopilot control algorithms for aircraft employing electric and magnetic field sensors. Electric and magnetic field sensors may be employed to augment other sensors to provide a capability of autonomous flight navigation in the near Earth space. The research builds upon the work performed by Physical Optics Corporation under an SBIR entitled Electric and Magnetic Photonic Sensor System for Small UAVs. Under the SBIR, Physical Optics will develop a small lightweight electric and magnetic sensor capable of providing the information necessary to detect and avoid or engage sources of electric and magnetic fields suitable for unmanned aircraft. The first control algorithms developed would be for the purpose of obstacle avoidance of power lines. In the future, these algorithms may be extended to use the electric and magnetic fields emanating from power lines and other sources as navigational aids. The paper will discuss development of flight control algorithms compatible with the Physical Optics sensors within a flight simulation environment. The paper should provide information about the interface between the electric and magnetic field sensors and the autopilot. The flight simulation will be performed in a hardware in the loop simulation with an autopilot.

9076-20, Session 5

Visulaized remote automatic aiming system through cooperative dual-field imaging

Yuqing He, Kun Huang, Shan Wei, Siyuan Wang, Jing Pan, Beijing Institute of Technology (China)

The traditional light weapon's working procedure is completed by manual operation. Each step, such as, searching, aiming and firing must be done by experienced sniper. Though advances in the firearms manufacturing level, the effect and precision of firing are not very stable due to a number of factors, especially the human factor. As the human heart beat, as well as vibrations caused when shooting, these factors will make the gun body quiver. And the quiver will cause large errors when the distance between the target and sniper rifle is far. Thus, a stable platform is very important. On the other hand, long hours work makes sniper produce fatigue, so that deviation occurs when sniper predict the target position. So a visualized remote automatic aiming and controling system is import. This paper proposed an automatic targeting system based on dual-field imaging.

The system consists of wide field of view (WFOV) camera and narrow field of view (NFOV) camera. With the expansion of the monitored area, WFOV camera is used to meet the requirements. Since it will produce different degrees of distortion, it has limited accuracy. And large FOV decreases the resolution of target. So we adopts the NFOV camera to do the precise aiming. Based on the above, a cooperative dual-field remote aiming system is designed. To grasp the overall situation, WFOV camera module is a static camera used for the observation of the sceneray information and give the target's coarse position; NFOV field camera module is a PTZ (Pan / Tilt / Zoom) camera for clear imaging and precise aiming for distant targets and tracking the target.

The two cameras are put together with the light weapon. Both cameras' video output will be send through a cable to the main processing unit which is far behind the imaging and firing system. The cable also works as communication and control signal feedback link. Through the working condition, we can design the specific parameters of the dual-field cameras and the structure of the control unit. User observe the dual field information through the monitor. If suspicious target appears, through the video of WFOV camera, we can do the automatic target detection. The location information is passed to the NFOV camera system through the control unit at the same time. Then it will control the PTZ camera will automatically move to the nearest node, which has calibrated, from the target. And then, NFOV camera module will track the target in real-time, and detect the face area of target.

Besides the hardware platform, the tracking algorithm is also a key issue in the whole system. In any case, the accuracy of targeting suspicious, depending on effectively track the target in real time, as well as the key parts of target location and detection. The TLD (tracking-learning-detection) algorithm, which was recently attracted widespread attention as an effective video tracking algorithm, has been improved to use in this system. Adaboost classifiers based on haar features is used to classify the target scene that find the human target in narrow-field, which replaces manually mark targets in conventional manner. Kalman filter is integrated in the TLD detector, estimate the target area, reduce the detection range of the detector, and increase the processing speed of the detector. Integrate particle filter algorithm into target detection, a method which based weighted observation model is proposed, i.e. weighted express the observation model with object detection result which base the improved TLD and the object color model. This method improves the detector's ability to identify and make better handle occlusion. Then, in the target area, the face detected by the Adaboost classifier, thereby real-time PID control via the main processing unit on the PTZ camera's rotation, tilt angle, so that the objectives in the field of view the central and sniper can accurately determine the firing zone.

Experiment result of testing the proposed system and algorithm prove this whole system has robust target tracking performance. It also proved that this system solves the contradiction between monitored field size and clarity of vision, it can be used in environments with poor outdoor places, with better robustness.

9076-21, Session 6

Polarimetric sensor systems for airborne ISR

David B. Chenault, Joseph L. Pezzaniti, John S. Harchanko, Polaris Sensor Technologies, Inc. (United States)

Polarimetric sensors measure not only the conventional intensity but also one or more parameters of the polarization ellipse. Measurement of the polarization content of a scene frequently offers additional contrast that is not readily apparent or is not measured at all with the conventional imager. Such polarimetric imaging systems, particularly in the infrared, have shown significant promise for detection of otherwise hard to find objects. Nearly two decades of data collection with scientific instruments has shown improved detection of ground vehicles, camouflaged and concealed targets, and maritime vessels from both ground and airborne platforms. These scientific instruments however have been large, not real-time, and frequently required static scenes and stable platforms.

Polarimetric imaging has seen significant advancement over the last decade and small, real-time infrared polarimetric cameras are now available that can be applied to airborne ISR missions. In this paper, we describe such an imaging polarimeter system, show some preliminary results (both still and video) that demonstrate the enhanced contrast possible with such systems, and discuss ways in which this system could be integrated with existing manned and unmanned platforms.

9076-22, Session 6

Real-time aerial multispectral imaging solutions using dichroic filter arrays

Dave Fish, John Dougherty, Pixelteq, Inc. (United States)

The next generation of multispectral sensors and cameras needs to deliver significant improvements in size, weight, portability, and spectral band customization to support widespread deployment for a variety of purpose-built aerial, unmanned, and scientific applications. The benefits of multispectral imaging are well established for applications including machine vision, biomedical, authentication, and aerial remote sensing environments – but many solutions require more compact, robust, and cost-effective production cameras to realize these benefits. A novel implementation uses micro-patterning of dichroic filters into Bayer and custom mosaics, enabling true real-time multispectral imaging with simultaneous multi-band image acquisition. Consistent with color camera image processing, individual spectral channels are de-mosaiced with each channel providing an image of the field of view. The additional spectral content provides additional data for scenarios like tracking, stand off chemical detection, and improved target acquisition. The application-specific dichroic filter array approach also reduces payloads and increase range for unmanned systems, with the capability to support both handheld and autonomous systems. We demonstrate recent results of 4-9 band dichroic filter arrays in multispectral cameras using a variety of sensors including linear, area, silicon, and InGaAs. Specific implementations range from hybrid RGB + NIR sensors to custom sensors with application-specific VIS, NIR, and SWIR spectral bands. Benefits and tradeoffs of multispectral sensors using dichroic filter arrays are compared with alternative approaches – including their passivity, spectral range, customization options, and development path. Finally, we report on the wafer-level fabrication of dichroic filter arrays on imaging sensors for scalable production of multispectral sensors and cameras.

9076-23, Session 6

9-band SWIR multispectral sensor providing full-motion video

Mary R. Kutteruf, Michael K. Yetzbacher, Andrey V. Kanaev, U.S. Naval Research Lab. (United States); Michael J. DePrenger, Tekla Research, Inc. (United States); Larry Vair, Jeffrey J. Pool, Pixelteq, Inc. (United States)

Short wave infrared (SWIR) sensors are becoming more common in DoD imaging systems because of their haze penetration capabilities and spectral properties of materials in this waveband. Typical SWIR systems have provided full motion video (FMV) with framing panchromatic systems and spectral imagery with line-scanning multi-spectral (MS) and hyperspectral systems. The system described here bridges these modalities, providing FMV with nine discrete spectral bands. Nine pixel sized SWIR filters are arranged in a repeating 3x3 pattern and mounted on top of a COTS, 2D staring focal plane array (FPA). We report on the filter construction and placement for the system and show laboratory measurements of the spatial and spectral response. Analysis of data collected with this camera using narrow band sources reveals subtle details of the FPA optical response. Field testing of the system was performed to allow for verification of the laboratory measurements and comparison to other sensors. Field test results from the nine-band system are compared with synthetic imagery constructed from data collected with a line-scanning hyperspectral imaging (HSI) system. Synthetic imagery constructed from HSI data using measured system component characteristics matches well with the nine-band data.

9076-24, Session 6

Compact LWIR hyperspectral system design and manufacturing considerations

Richard L. Wiggins, Lovell E. Comstock, Patrick Woodman, Corning Specialty Materials, Inc. (United States)

The scale of LWIR hyperspectral imaging systems is driven by the large LWIR camera. As microbolometer FPAs become more sensitive, and as cryo-cooling for MCT LWIR FPAs becomes compact, the desired size of the LWIR spectrograph will shrink. Corning Advanced Optics has anticipated the requirements of a high-throughput, tiny, LWIR spectrograph and has applied its monolithic manufacturing techniques to meeting this need.

This paper will discuss the dimensions, potential system performance and manufacturing milestones of an f/0.9, 7.3-14.5 [um], all reflective, Offner type, monolithic spectrograph. System tradeoffs, optical design, and optical performance will be examined.

9076-25, Session Posters-Thursday

Robust real-time horizon detection in full-motion video

Grace B. Young, La Jolla High School (United States); Bryan Bagnall, Corey Lane, Shibin Parameswaran, Space and Naval Warfare Systems Ctr. Pacific (United States)

The ability to detect the horizon on a real-time basis in full-motion video is an important capability to aid and facilitate real-time processing of full-motion videos for the purposes such as object detection, recognition and other video/image segmentation applications. In this paper, we propose a method for real-time horizon detection that is designed to be used as a front-end processing unit for a real-time marine object detection system that carries out object detection and tracking on full-motion videos captured by ship/harbor-mounted cameras, Unmanned Aerial Vehicles (UAVs) or any other methods surveillance for Maritime Domain Awareness (MDA). Unlike existing horizon detection work, we cannot assume a priori the angle or nature (straight line) of the horizon, due to the nature of the application domain and the data. Therefore, the proposed real-time algorithm is designed to identify the horizon at any angle and irrespective of objects appearing close to and/or occluding the horizon line (for e.g. trees, vehicles at a distance) by accounting for its non-linear nature. We use a simple two-stage hierarchical methodology, leveraging color-based features, to quickly isolate the region of the image containing the horizon and then perform a more fine-grained horizon detection operation. In this paper, we present our real-time horizon detection results using our algorithm on real-world full-motion video data from a variety of surveillance sensors like UAVs

and ship mounted cameras confirming the real-time applicability of this method and its ability to detect horizon with no a priori assumptions.

9076-26, Session Posters-Thursday

Fusion of thermal infrared and visible spectrum for robust pedestrian tracking

Moulay A. Akhloufi, Ctr. of Robotics and Vision (Canada) and Laval Univ. (Canada); Abdelhakim Bendada, Xavier P. V. Maldague, Univ. Laval (Canada)

Tracking pedestrians is an area of computer vision that has attracted a lot of interest in recent years. Many of these work was conducted in the visible spectrum. Some work was also conducted in thermal infrared spectrum. The majority of the research work used one spectrum at a time. In this work, we present a fusion framework using thermal infrared and visible spectrums in order to robustly track the detected moving objects. The detected objects are then processed using HOG features in order to classify them as a pedestrian or a non-pedestrian using SVM. The tests were conducted in outdoor scenarios. The obtained results are promising and the show the efficiency of the proposed framework.

9077-1, Session 1

FPGA architectures for electronically scanned wideband RF beams using 3D FIR/IIR digital filters for rectangular array aperture receivers

Sewwandi Wijayaratna, Brandon D. Beall, Arjuna Madanayake, The Univ. of Akron (United States); Len Bruton, Univ. of Calgary (Canada)

The paper discusses three-dimensional (3-D) digital filtering algorithms and FPGA based hardware prototype circuits for achieving electronically steerable ultra-wideband RF beams for rectangular-array aperture receivers. The proposed 3-D FIR/IIR filters are of significantly lower computational complexity compared to traditional phased-array realizations. Rapidly steerable RF beams are important in electromagnetic sensing and imaging systems which receive signals from fast moving targets having low radar cross section (RCS) under severe jamming. Digital 3-D FIR cone filters are highly steerable in any required direction while maintaining guaranteed stability and linear phase response over an ultra-wideband of RF frequencies. Digital 3-D IIR cone filters achieve highly selective cone shaped RF beams at an order of magnitude lower multiplier complexity compared to FIR filters at the cost of non-linear phase response. The paper provides an overview of the design, simulation, and FPGA based rapid prototyping of both FIR and IIR 3-D digital cone filters which are based on partially separable 2-D FIR/IIR spatio-temporal fan/beam filter building blocks. The 2-D FIR/IIR fan/beam filter building blocks have filter coefficients which are defined using algebraic closed-form expressions that are functions of desired beam personalities including the look-direction of the aperture, the bandwidth and sampling frequency of interest, inter antenna spacing in the aperture array, and beam size. Application specific computing units for rapidly calculating the filter coefficients in nanoseconds allows fast real-time tracking of low RCS objects at close range. FPGA based designs and on-chip hardware co-simulations are provided to show the potential for real-world application of the fully digital 3-D RF beamformers.

9077-2, Session 1

Linearization of a harmonic radar transmitter by feed-forward filter reflection

Kyle A. Gallagher, The Pennsylvania State Univ. (United States); Gregory J. Mazzaro, The Citadel (United States); Kelly D. Sherbondy, U.S. Army Research Lab. (United States); Ram M. Narayanan, The Pennsylvania State Univ. (United States)

Harmonic radar exploits the difference in frequency between radar waves that illuminate electromagnetically nonlinear targets, such as radio-frequency (RF) electronics, and the waves that reflect from those targets. The advantage of harmonic radar over traditional linear radar is high clutter rejection, as most naturally-occurring (clutter) materials do not exhibit a nonlinear electromagnetic response under illumination by RF energy. The disadvantage of harmonic radar is that the transmit power required to detect a nonlinear target is relatively high, and care must be taken to ensure that the transmission of such high power does not generate distortion that might mask the target response.

A high-power, linearized harmonic radar tailored to a set of RF electronic responses would help law enforcement agents to locate devices whose emissions exceed those permitted by law, allow security personnel to detect unauthorized radio electronics in restricted areas, or enable first-responders to pinpoint personal electronics during emergencies such as immediately after an avalanche or earthquake.

A novel method for simultaneously achieving high power and high linearity for a harmonic radar transmitter is presented; it is called feed-forward filter reflection (FFFR). Reduction of a particular system-generated harmonic is accomplished by combining a phase-shifted version of the undesired harmonic reflected from a low pass filter with the desired transmission passing through the filter. The FFFR technique achieves –90 dBc harmonic distortion, at 4 W output power, at transmit frequencies between 800 MHz and 1 GHz. This degree of linearity is comparable to the cancellation achieved using iterative, automated feed-forward techniques. Implementation of FFFR is most appropriate when attenuation of a particular undesired harmonic is necessary and attenuation of the desired transmission by additional filtering is unacceptable.

9077-3, Session 1

Characterization of carbon fiber composite materials for RF applications

Elliot J. Riley, Erik H. Lenzing, Ram M. Narayanan, The Pennsylvania State Univ. (United States)

Carbon Fiber Composite (CFC) materials have been used for decades in the aerospace, automotive, and naval industries. They have often been used because of their mechanical advantages. These advantageous characteristics have typically included low weight and high strength. It is also beneficial for structural requirements that CFC materials can be made into many shapes and sizes.

With the abundant use of CFC materials, it has been the focus of more recent research to investigate the electrical characteristics of these materials. CFC materials consist of a non-conductive resin or epoxy and of course conductive carbon fibers. The carbon fibers can be oriented and layered in many different configurations. The specific orientation and layering of the carbon fibers has a direct impact on the electrical characteristics.

One specific characteristic of interest is the conductivity of CFC materials. Conductivity can be assed in a static DC sense and in response to an electromagnetic wave. Knowledge of the conductivity of different CFC materials can potentially lead to using CFC materials for RF applications. These applications may include but are not limited to antenna designs, shielding enclosures, radar reflectors, radar absorbers, or even microstrip circuits.

The work in this paper deals with probing the conductivity characteristics of CFC materials. Multiple styles of carbon fiber are investigated. The DC conductivity was measured by applying a conductive epoxy and using a milliohm meter. The response of CFC materials to electromagnetic waves was explored using radar cross section measurements, free space reflection measurements, and by using experimental microstrip lines.

Keywords: carbon fiber composite (CFC) materials, conductivity characterization, radar applications of CFC materials

9077-4, Session 1

Tapered slot array antenna design for vehicular GPR applications

Korkut Yegin, Yeditepe Univ. (Turkey); Emrullah Bicak, Hakkı Nazlı, Mahmut Dağ, TÜBITAK BILGEM (Turkey)

Vehicular applications of UWB GPR demand multiple GPR sensors operating in a harsh environment. One of the key elements of in the sensor is its UWB antenna which has minimal inter-element coupling, low group delay, high directivity and less prone to environmental conditions. Tapered slot antennas (TSA's) provide good impedance match, but they need to be modified for GPR specifications. Parasitic slot loaded TSA with balanced feed is proposed and a multi-channel antenna array structure is formed. Structural parameters are numerically analyzed and a prototype is built. Measurements show good performance for UWB GPR applications.

9077-5, Session 2

Multi-mission, autonomous, synthetic aperture radar

Thomas J. Walls, Michael L. Wilson, U.S. Naval Research Lab. (United States); David Madsen, Mark D. Jensen, Stephanie W. Sullivan, Space Dynamics Lab. (United States)

Unmanned aerial systems (UAS) systems have become a critical asset in current battlespaces, and continue to play an increasing for intelligence, surveillance and reconnaissance (ISR) missions. With the development of medium-to-low altitude, rapidly deployable aircraft platforms, the ISR community has seen an increasing push to develop ISR sensors and systems with real-time mission support capabilities. This paper describes recent flight demonstrations and test results of the RASAR (Real-time, Autonomous, Synthetic Aperture Radar) sensor system. RASAR is a modular, multi-band (L and X) synthetic aperture radar (SAR) imaging sensor designed for self-contained, autonomous, real-time operation with mission flexibility to support a wide range of ISR needs within the size, weight and power constraints of Group III UASs. The sensor command and control and real-time image formation processing are designed for integration of RASAR into larger, multi-intelligence system of systems. The multi-intelligence architecture and a demonstration of real-time autonomous cross-cueing of a separate optical sensor will be presented.

9077-6, Session 2

Multi-polarization foliage penetration classification results from a SWaP limited multifrequency SAR

Evan C. Zaugg, Joshua P. Bradley, Matthew C. Edwards, ARTEMIS, Inc. (United States)

Radar polarimetry has proven very useful for classification of targets, terrains, and land-cover. It is extensively used with satellite based SAR systems, and with a few airborne SAR systems. Typically an airborne SAR system with multiple frequencies and polarizations is a very expensive, one-of-a-kind, experimental development. Traditionally, a SAR system like this is flown on a large aircraft which can handle the large size, weight, and power (SWaP) specifications of the radar system, especially if the SAR employs the low-frequencies used for foliage penetration applications. Recently, high performance, inexpensive SAR systems with diverse capabilities and small SWaP requirements, such as the ARTEMIS SlimSAR, have been developed. The SlimSAR has been flown on a variety of small manned and unmanned aircraft and has demonstrated great versatility in meeting the needs of a variety of imaging scenarios. Exploiting the new capabilities offered by these new radars shows the potential for expanding the use of SAR polarimetry into applications and areas previously prohibited by high-costs and/or dangerous flight conditions. This paper presents the SlimSAR system, with imagery from both multiple polarizations and frequencies, including foliage penetration at P-band. We also discuss the issues involved in applying polarimetric classification techniques to this type of radar. Included are discussions and demonstrations of different methods of polarization calibration of the SlimSAR, as well as different image classification methods that exploit scattering mechanisms through polarimetric decomposition based on the alpha-entropy plane. When used in conjunction with the complex Wishart classifier, we show that terrain classification helps to reduce false alarm rates for sub-foliage target detection.

9077-7, Session 2

A wideband holographic radar system for multi-dimensional high-resolution imaging

Scott A. Wilson, Ram M. Narayanan, The Pennsylvania State Univ. (United States)

Over the last 50 years, principles established in optical holography have been demonstrated in the microwave regime. In the early stages of development, microwave holograms were recorded on film or other types of analog media and image reconstitution could be performed only by physically illuminating the hologram with a coherent optical source. Advancements in data acquisition systems and signal processing algorithms have made it possible to numerically reconstruct a target scene from a digitally-recorded hologram. Most recently, fast Fourier transform (FFT) methods have been able to demonstrate high-resolution image reconstruction of a digitally-recorded hologram in nearly real-time. Using a coherent microwave radar system, interference patterns produced by a scattering target can be measured and recorded as a digital hologram, after which the original target scene may be reconstructed using an FFT-based reconstruction algorithm. For systems operating at single-frequency, the reconstruction algorithm provides the ability to re-focus a two-dimensional image to any single focal depth. Wideband systems yield an additional dimension for range resolution, thereby extending the focal depth to where scattering fields produced by three-dimensional geometries can be resolved into a well-focused surface volume.

Compared to optical imaging systems, advantages to the wideband holographic radar include the ability to penetrate common materials and structures, retain phase and amplitude information of scattered fields, as well as being able to measure and numerically reconstruct target information in multiple dimensions. For these reasons, a simple wideband holographic radar system has been developed for measuring the backscattered fields from an illuminated target scene. Measurements are made over an 80 cm x 80 cm rectilinear planar aperture using a quasi-monostatic antenna pair for transmit and receive. Wideband measurements are made over step-frequencies between 10-20 GHz for a theoretical range resolution of 15 mm. The FFT-based reconstruction algorithm has been demonstrated on a basic simulation model, as well as on experimental data. Future work in this research may include polarimetric hologram reconstruction, as well as super-resolution imaging techniques.

9077-8, Session 2

Design and performance of an ultra-wideband stepped-frequency radar with precise frequency control for landmine and IED detection

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The Army Research Laboratory (ARL) has developed an impulse-based vehicle-mounted forward-looking ultra-wideband (UWB) radar for imaging mines and providing through-the-wall sensing. As part of ARL's Partnerships in Research Transition (PIRT) program, there is a new effort to address deficiencies of the impulse radar system with a Stepped-Frequency Radar (SFR) which allows for precise control over the radiated spectrum, while still maintaining an effective ultra-wide bandwidth. The SFR utilizes a frequency synthesizer which can be configured to excise prohibited and interfering frequency bands and also implement frequency-hopping capabilities. The SFR is designed to be a forward-looking ground-penetrating (FLGPR) Radar utilizing a uniform linear array of 16 Vivaldi receive antennas and two (2) Quad-ridge horn transmit antennas. The SFR has an operating frequency band which ranges from 300–2000 MHz, and a minimum frequency step-size of 1 MHz. The radar system is capable of illuminating range swaths that have maximum extents of 30 to 75 meters (programmable). The transmitter has the ability to produce approximately -6 dBm/MHz average power over the entire operating frequency range. The SFR will be used to determine the practicality of detecting and classifying buried and concealed landmines and improvised explosive devices (IEDs) from safe stand-off distances.

This paper discusses the current status and expected performance of the SFR, as derived from laboratory testing. Key to spectrum management is the precise control of selected frequencies across the UWB spectrum. Specifically, frequency notching is needed to be permitted to operate at various test sites for system design & evaluation purposes for developmental

systems. However, on the battlefield with so many other spectrum users, the SFR will need to co-exist and to do so will need to omit transmitting as to not interfere with other critical battlefield systems. Thus, a technical issued to be addressed in this paper is the problem of omitting frequencies which manifests as artifacts in the range profile which appear as undesired range sidelobes. A study of this effect is presented, which discusses pre- and post-processing of the data which can limit these confounding perturbations. In addition, the paper will discuss mitigation of self-generated harmonics, integration of GPS/IMU for geo-spatial target detection and electronic marking, and other technical upgrades.

9077-10, Session 3

Design of a synthetic aperture radar synthetic scene generator

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For airborne synthetic aperture radars a flight test is required to completely characterize its system-level performance. However, flight testing can be expensive especially when problems arise and the flight testing time increases costs. It would be beneficial to complete as much system testing as possible in the laboratory environment. Several tests exist for testing subsystems and components, however it is very important that the entire system is tested as it would operate in flight. Typical laboratory tests use a delay line to create a single point target. This is a very important test, however to produce a clean IPR requires modifications to the image formation or data collection algorithms because the delay line does not behave as a real point target. We desire to create a complete system test where an arbitrary number of point targets and clutter patterns combine to mimic radar responses from a real scene. This would enable a complete test of the radar system in the laboratory environment according to prescribed terrain/scene characteristics.

This paper presents an overview of the system requirements for a synthetic scene generator. The analysis is limited to synthetic aperture radar systems utilizing chirp waveforms and stretch processing. Relationships between IF bandwidth, target position, and the phase history model are calculated. A technique to properly compensate for motion pulse to pulse is presented. The concept is demonstrated with simulation data.

9077-11, Session 3

Improving target position and velocity estimation for air-to-air radar

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General Atomics Aeronautical Systems, Inc. (GA-ASI) has designed and prototyped an air-to-air radar to provide Due Regard and Sense and Avoid capabilities for Remotely Piloted Aircraft (RPA). This radar employs a Search While Track (SWT) mode to perform target detection, acquisition, and tracking in a search volume. SWT utilizes a set of Kalman filters (KFs) for implementing multi-target tracking. The track on target is declared as the track accuracy (quantified in terms of estimated target position and velocity accuracies) satisfies a certain criterion which is derived from the RPA safety requirement.

Since the KFs are designed to handle tracking of maneuvering targets, a large amount of updates may be needed to achieve the required track accuracy if there is any mismatch in the target maneuvering model. Post-KF processing is therefore needed to improve the track accuracy in order to achieve a reliable track declaration efficiently. In this study, a Weighted Least Square (WLS) estimator and an alpha-beta filter are used as the post-KF processing methods to refine the KF outputs. Computational requirement and structural complexity and expandability are analyzed and compared for practical implementations of both methods. Monte Carlo simulations are conducted to demonstrate their effectiveness. Simulation results and performance comparison between the two post-KF processing methods will be provided in the full paper.

9077-12, Session 3

Identification of maritime target objects from high resolution TerraSAR-X data using SAR simulation

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In general, interpretation of signatures from synthetic aperture radar (SAR) data is a challenging task even for the expert image analyst. For the most part, this is caused by radar specific imaging effects, e.g. layover, multi-path propagation or speckle noise. Specifically for the application in maritime security, ship signatures exhibit additional defocusing effects due to the ship's movement even when they are anchored. Focusing on object recognition, the detection of target signatures can be done with a pretty good chance of success, but the identification is often impossible.

To assist image analysts in their recognition tasks, a SAR simulation tool has been developed recently. It is very simple to operate, by simulating available 3D model data of ships and test the resulting simulated signatures with their real counterpart from SAR images. This is a very robust way to identify larger vessels out of current one meter resolution space borne SAR data like from TerraSAR-X. Nevertheless, for smaller vessels this can be still very challenging, because the resolution is too coarse. Recently, TerraSAR-X initiated a new staring spotlight imaging mode that enhances cross-range resolution significantly and therefore also improves the chance for the identification of smaller vessels.

This paper demonstrates the capabilities of the developed simulation tool in assisted target recognition specifically on ship signatures. The improvement of recognizability will be studied by comparing identification performance for TerraSAR-X sliding spotlight mode and staring spotlight mode data.

9077-13, Session 3

A complete ensemble empirical mode decomposition for GPR signal time-frequency analysis

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Time-frequency analysis plays a significant role in GPR data processing and interpretation. Due to the mixing frequency problem in GPR signal, the empirical mode decomposition (EMD) method can not separate and extract the weak target information effectively. In this paper, an algorithm based on the complete ensemble empirical mode decomposition (CEEMD) is presented. The key idea on the CEEMD relies on averaging the modes obtained by EMD applied to several realizations of Gaussian white noise added to the original signal. The resulting decomposition solves the EMD mode mixing problem. Analysis on GPR synthetic and real data show that the CEEMD can effectively eliminate the mode mixing problem in EMD, which means different frequency scales in GPR signals are decomposed in different Intrinsic Mode Functions (IMF). Furthermore, this method can restrain the noise in the original signal and more detail information can be seen clearly in the time-frequency spectrum. It demonstrates that this method promises higher spectral-spatial resolution than the ensemble empirical mode decomposition (EEMD). Application this method on GPR signals, such as through wall GPR and surface GPR thin layer detection, thus offers the potential of highlighting data processing and signal analysis.

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9077-66, Session 3

Spectrum sensing techniques for nonlinear radar

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The phenomenon of inducing a nonlinear response in metallic objects and electronics has been investigated extensively throughout the years. In many applications the nonlinear response manifests itself as interference in electronic systems and is typically disruptive. In other applications radars have been specially designed to exploit and detect nonlinear responses of targets. These radars are known as nonlinear radars. Nonlinear radar requires more power-on-target for a signal to noise ratio (SNR) equivalent to that of traditional linear radar. Nonlinear radar is further challenged by the cluttered electromagnetic environment (EME) since the signal-to-interference-plus-noise ratio (SINR) decreases due to interfering signals. This problem is becoming significant as the available frequency spectrum shrinks due to growing wireless communication device usage and changing regulations. A possible solution to these challenges is spectrum sensing, a technique employed by cognitive radio to monitor the RF spectrum for channel availability and the activity of the primary (i.e. the licensed) user. In this paper, spectrum sensing techniques and their complexity are investigated for nonlinear radar. It will be shown how these techniques are used to identify transmit and receive frequencies of interest based on a multiband energy detection framework.

9077-15, Session 4

Indoor clutter spectral characteristics and radar waveform design

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This paper investigates the use of the spectral properties of stationary human targets and indoor clutter for waveform design. The paper focuses on analysis and comparison between stationary human targets and that of common indoor clutter by comparing modeling results using Finite Difference Time Domain (FDTD). Using FDTD techniques allows us to examine the radar cross section (RCS) of humans and indoor clutter objects by using different types of computer models. FDTD allows for the spectral characteristics to be acquired over a wide range of frequencies, polarizations, aspect angles, and materials.

The acquired RCS characteristics are then applied to the optimization of radar waveforms for target emphasis. Based upon variables such as frequency, polarization, and aspect angle, the separation between targets and clutter are used in a water filling approach to utilize the information between targets and clutter. The optimized waveform is then applied to experimental scenarios to compare and contrast target emphasis and clutter suppression.

9077-16, Session 4

Textural feature selection for enhanced detection of stationary humans in through-the-wall radar imagery

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Feature-based methods have been recently considered in the literature for detection of stationary human targets in through-the-wall radar imagery [1]. Specifically, textural features, such as contrast, correlation, energy, entropy, and homogeneity, have been extracted from gray-level co-occurrence matrices (GLCMs) to aid in discriminating the true targets from multipath ghosts and clutter that closely mimic the target in size and intensity. A GLCM is the spatial-dependence probability-distribution matrix of pairs of pixels separated by a given offset in a particular direction [2]. Texture information extracted from GLCMs exposes the local variations of the image, thereby enabling the spatial inter-relations of neighboring patterns of pixel values within the target and the ghost/clutter images to be captured. In this paper, we address the task of feature selection to identify the relevant subset of features in the GLCM domain, while discarding those that are either redundant or confusing, thereby improving the performance of feature-based scheme to distinguish between targets and ghosts/clutter. We apply a Decision Tree algorithm to find the optimal combination of co-occurrence based textural features for the problem at hand. We employ a K-Nearest Neighbor (KNN) classifier [3] to evaluate the performance of the optimal textural feature based scheme in terms of its target and ghost/clutter discrimination capability and use real-data collected with the Multi-channel TWSAR, which is the vehicle-borne through-the-wall radar imaging system by Defence Research and Development Canada (DRDC). The dataset corresponds to through-the-wall measurements of multiple humans of different heights, standing or sitting at different downranges in a small room. For the specific data analyzed, it is shown that the identified dominant features yield a higher classification accuracy, with lower number of false alarms and missed detections, compared to the full co-occurrence based feature set.

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9077-17, Session 4

High-order approximation compact schemes for forward subspace scattering problems

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In this paper, we develop an efficient iterative approach to the solution of the discrete three-dimensional Helmholtz equation with variable coefficients and PML boundary conditions based on compact forth and sixth order approximation schemes. The coefficient matrices of the resulting systems are not Hermitian and possess positive as well as negative eigenvalues so represent a significant challenge for constructing an efficient iterative solver. In our approach these systems are solved by a combination of a Krylov subspace-type method with a matching high order approximation direct preconditioner with coefficients depending only on one spatial variable. In the algorithms considered, the exact solution of high order preconditioning systems is based on a combination of the separation of variables technique and Fast Fourier Transform type methods. The resulting numerical methods allow for efficient implementation on parallel computers. Numerical tests confirm the high efficiency of the proposed iterative algorithms. The developed method is used to compute the scattered electrical field originated by Ground Penetrating Radar in the forward subsurface scattering problem. Numerical results for realistic ranges of parameters in soil and mine-like targets are presented. The impact of the order of approximation of the finite difference scheme and parameters of the PML layer on the accuracy of the approximate solution are considered.

9077-18, Session 5

GNSS-based passive airborne radar: Hybrid-aperture sensing and airborne test plans

Yan Zhang, Hernan Suarez, Randall Silver, Yih-Ru Huang, The Univ. of Oklahoma (United States)

Airborne ISR sensing using reflected GNSS signals as signal of opportunity is one of the promising solutions to LPI radar sensing, spectrum sharing, and multi-functional integration. A hybrid-aperture radar system consisting of an electronic scanning array at GPS frequency band and synthetic array processing is being developed by the Intelligent Aerospace Radar Team (IART) at the University of Oklahoma. In addition to the covertness of ISR operation and reduced SWaP, the advantages of the hybrid-aperture system include reduced computational complexity of onboard processor, good phase coherency, integration with GNSS navigation system and potential multiple functionalities. During the recent laboratory prototyping and ground tests, a real aperture, scanning array contains 32 active elements and scan in azimuth direction with about 3 degree beam resolution has been demonstrated, and initial images of ground building targets are obtained. The images show clear consistency of target signatures for different satellite positions, while the detailed information observed from the images are greatly affected by the selection of satellite vehicles and real-time constellations. The current imaging formation algorithms used standard carrier phase tracking together with the non-coherent energy integration. The planned flight test will continue to use both downward looking and side-looking modes. Based on current EM simulations, a low-cost, left-hand-polarized (LHP) conformal array will replace the bulky right-hand-polarized (RHP) array for ground experiments. The software-defined backend is being designed to be better air-worthy. The image formation algorithms are being improved to include more accurate real-time satellite constellation information as well as coherent back-projection.

9077-19, Session 5

A universal hardware-based adaptive correlation receiver architecture

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In this study, we investigated a hardware-implementation of closed-loop, adaptive radar transceiver architecture especially designed for low-probability of intercept (LPI) radar employing diversified waveforms. At the transmitter side, adaptive pre-distortion is implemented through memory polynomial models, in order to improve the linearity of solid-state transmitter responses. At the receiver side, similar processing is incorporated for post-distortion through kernel-LMS, which effectively reduces the sidelobe distortions from target signatures. These transmitter optimization techniques can be extended to a fully adaptive transmission scheme with targets presenting in the loop. Furthermore, real-time FPGA implementation of adaptive pulse compression (APC) is demonstrated, and the detailed performance data are obtained. It is envisioned that all these elements can be built into an embedded and reconfigurable module to be inserted into an existing radar transceiver, and transform it to fully-adaptive operations. A Ku-band testbed system with arbitrary waveform processing functionality is implemented, together with a low-cost RF channel emulator, which can function as both point-target emulator and a variable delay-line in receivers. The new receiver architecture concept is being tested and demonstrated on this testbed for real-time operations.

9077-20, Session 5

Ultra-wideband noise radar imaging of a cylindrical PEC object using diffraction tomography

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Imaging technique has been used for a long time in many applications, and advances in signal and imaging processing technique of radar systems have progressed so that the multi-dimensional images of the target object are successfully reconstructed using various input waveforms. Transmitting ultra-wideband (UWB) random noise waveform guarantees the immunity from jamming and interference, low probability of detection and interception; however, not many tomographic imaging literatures using UWB random noise waveforms in frequency domain have been published yet. This paper presents the theoretical analysis of Fourier diffraction tomography based on multiple transmissions of independent and identical distribution (iid) of UWB noise waveforms for a given two dimensional geometry. A stationary PEC cylindrical object is illuminated by multiple iid UWB noise waveforms, and a receiver array is positioned at one side of the imaging geometry to collect the backward scattered field.

In the paper, we show that a single transmission of a random noise waveform may not sufficient to obtain a successful object image for the desired frequency ranges. In order to bypass a shortcoming of the single transmission of the random noise waveform, multiple iid random noise waveforms with a frequency range from 8 GHz to 10 GHz are transmitted to reconstruct a final image of the object. Diffraction tomography theorem is applied for each noise waveform transmission so that the image of the object is reconstructed based on the backward scattered field at the end of each noise waveform transmission case. When all iid noise waveforms are transmitted, the final tomographic image of the target is reconstructed by averaging all obtained images from multiple transmissions. Several numerical simulations in spatial frequency domain are performed, and the successful tomographic image of the cylindrical PEC object is achieved after transmission of multiple iid UWB random noise waveforms.

9077-21, Session 5

SAR image reconstruction using advanced pulse compression noise (APCN)

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This work demonstrates the feasibility of using the advanced pulse compression noise (APCN) radar waveform for RF secure, synthetic aperture radar (SAR) applications. Using a simple image reconstruction technique, we are able to form simulated images and compare the range point spread function (PSF) for a nominal point target with that of a conventional pulse linear-FM (LFM) chirp signal. We show that the desired resolution for the APCN case is only marginally affected by high correlation sidelobes, and that the sidelobe levels are sufficient for most synthetic aperture imaging applications. For thoroughness, different carrier frequencies and sidelobe weighting schemes will be evaluated based on what impact they may have on SAR image quality.

9077-22, Session 5

Influence of signal parameters in noise radar sensor technologies used for sensing through dispersive media

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The frequency dispersive behavior of natural media such as soil, vegetation, water, and atmosphere, can lead noise radar techniques and sensors to unexpected inaccuracies in their performance due to the likely appearance of the precursor electromagnetic signals. The formation of these precursor fields is related to the chosen frequency spectrum window, the desired frequency signal bandwidth, and the selected shape of the transmitted signal.

For frequency-dependent media, the propagated signal then, becomes a critical part of the system and the final performance depends on its proper configuration because this latter can decide the formation or absence of the precursor field which appears as an additional component superimposed to the propagated signal.

In case of a precursor arising out, the distortion undergone by the signal transmitted through or reflected on a dispersive medium basically consists of amplitude level modification and spreading of the pulse width duration. These alterations introduce uncertainty in the received signal making the information retrieval difficult and inaccurate.

However, the formation of the precursor fields can improve the propagation by offering significantly better signal-to-noise ratio to achieve an enhanced sensing capability.

Experimentally for a random noise signal in the THz band, we have estimated that precursors can occur in a different way according to the input pulse setting.

We examine the theoretical evolution of various waveform shapes through water, soil and vegetation. Measurements carried out in the THZ band provide an experimental verification of the precursor formation through water for random noise signals.

9077-23, Session 5

Superresolution processing for multifunctional LPI waveforms

Zhengzheng Li, Shang Wang, Jingxiao Cai, Yan Zhang, The Univ. of Oklahoma (United States)

Low-probability-of-intercept (LPI) waveforms can be used in multi-functional radar operations and provides specific features for specific missions. This study focuses on the adaptive pulse compression (APC) –based super-resolution processing on different LPI waveforms and evaluates the performance tradeoffs from mainly the algorithm perspective. In practice, there are tradeoffs among the length of the adaptive filter, waveform characteristics, signal-to-noise ratio, and receiver sampling strategies, and a combination of these factors have significant effect on the achievable resolution and SNR. The underlying mechanisms of algorithms and statistics resulting in these tradeoffs are explored. It is possible to tune the processing algorithms to achieve the optimal results for specific waveforms. Examples are mainly given for random phase coded waveforms (such as PPM/PM waveforms used in ADS-B radar), LFM and random noise waveforms. Performance for complex impulse response estimation (for both amplitude and Doppler) for different types of target and clutter will be analyzed. Traditional matched-filter and mismatched-filter suffer from the waveform-dependency. The robustness of APC with respect to the waveform variation will be demonstrated (e.g. APC has high tolerance to PPM/PM modulation).

The adaptive super-resolution processing is also extended to two-dimensional real-beam imaging processing. Examples based on Ground-Based Sense and Avoid (GBSAA) radar experiments are provided and discussed. An adaptive radar scheme that achieves the “super-resolution on-demand” is introduced. With the solid-state GBSAA radar, we demonstrated that 2D image resolution can be adjusted based on the target region of interest, and optimal performance of SNR can be obtained for the selected resolution.

9077-24, Session 6

A combined STAP/DPCA algorithm for enhanced endoclutter target detection

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Displaced Phase Center Antenna (DPCA) and Space-Time Adaptive Processing (STAP) are two general methods to cancel clutter in order to detect small, slowly moving targets such as dismounts that may be obscured by clutter. To detect these targets, the radar detection threshold needs to be as low as possible to ensure some minimum probability of detection (Pd). Unfortunately, lowering the radar threshold naturally results in a higher false alarm rate. There are a number of false alarm mitigation techniques available to lower the false alarm rate. Although there are standard methods such as M of N to reduce the false alarms, new techniques can potentially drive the false alarm rate down even further.

Many “theoretical” papers have shown that STAP can be designed to outperform DPCA because of its potential additional “degrees-of-freedom.” However, in “practice,” this isn’t always the case. For example, it is well known that STAP can have training issues in heterogeneous clutter. Typically, a radar signal processor will implement one method or the other to detect these small endoclutter targets. The technique being explored here is a two-fold approach in which the existing STAP code first processes the data in order to find a list of candidate targets. Next, a DPCA technique is also used to find a separate list of candidate detections from the same data. Although the algorithms are working on the same data, the processing is “independent” between them so the target lists are different. After both techniques have finished processing, the modified radar signal processing code “intelligently” combines the two detection lists into a single detection list. It will be shown that the combined list of detections from the two methods results in better detection performance than either method by itself.

9077-26, Session 6

Image reconstruction and compressed sensing in MIMO radar

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MIMO radar utilizes the transmission and reflection of multiple independent waveforms to construct an image approximating a target scene. Compressed sensing (CS) techniques such as total variation (TV) minimization and greedy algorithms can permit accurate reconstructions of the target scenes from undersampled data. The success of these CS techniques is largely dependent on the structure of the measurement matrix. A discretized inverse scattering model is used to examine the imaging problem, and in this context the measurement matrix consists of array parameters regarding the geometry of the transmitting and receiving arrays, signal type, and sampling rate. We derive some conditions on these parameters that guarantee the success of these CS reconstruction algorithms. The effect of scene sparsity on reconstruction accuracy is also addressed. Numerical simulations illustrate the success of reconstruction when the array and sampling conditions are satisfied, and we also illustrate erroneous reconstructions when the conditions are not satisfied.

9077-27, Session 6

Optimal waveform design under employment of generalized detector in MIMO radar systems

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In this paper, we derive the optimal generalized detector (GD) and its

performance, and then present a methodology for the design of the transmit signal for a multistatic or MIMO radar receiver. The GD assumes a Swerling I extended target model as well as signal-dependent noise, i.e., clutter. It is shown that the GD detection performance does not immediately lead to an obvious signal design criterion so that as an alternative, a divergence criterion is proposed for signal design. A simple method for maximizing the divergence, termed the maximum marginal allocation algorithm, is presented and applied to find the global maximum. The overall approach is a generalization of previous work that determined the optimal GD and transmit signal for a monostatic radar systems.

9077-28, Session 6

Indoor facility for airborne synthetic aperture radar (SAR) explosive hazard experimentation: rail-SAR

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The Army Research Laboratory (ARL) is developing an indoor experimental facility to evaluate and assess airborne Synthetic Aperture Radar (SAR) based detection capabilities against explosive hazards. The rail-SAR facility is a multi-use facility that also provides a basis for robotic autonomy and navigational developmental research. Radar explosive hazard detection is one key sensor developmental area to be exploited at this indoor facility. In particular, the mostly all wooden multi-story building houses a two (2) story housing façade structure and an open area built over a large sandbox. The housing façade structure includes reconfigurable indoor walls which will provide for multiple See-Through-The-Wall (STTW) experimentation scenarios. Whereas, the open sandbox will allow for surface and buried explosive hazard experimentation deployment scenarios. The indoor facility is not rated for true explosive hazard materials so all targets will need to be inert and filled with surrogate dielectric explosive fills.

This paper discusses the current status and data collection efforts against canonical targets across ultra-wideband (UWB) airborne SAR frequencies of interest. A near-monostatic antenna configuration will be used to investigate airborne SAR parameters such as angles of depression, frequencies & bandwidths of interest, SAR-integration angles, and target burial depths, orientations, and type. Canonical targets will initially be used to evaluate overall facility capabilities and limitations. These aspects will be analyzed and summarized for future explosive hazard target deployments and associated assessments. This paper will also describe the processing techniques developed and applied to address RF multi-path, platform interference and Radio Frequency Interference (RFI) from indoor facility operations. Discussion of this facility and its capabilities and limitations will provide a context for future explosive hazard airborne SAR assessments.

9077-25, Session 7

Determining snow depth using Ku-band interferometric synthetic aperture radar (InSAR)

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Monitoring seasonal snow accumulation is important for evaluation of snow models, for short- and long-term snow cover monitoring, and for both military and civilian activities in cold climates. Improved spatial analysis of snow depth and volume can help decision makers plan for future events and mitigate risk. Current snow depth measurement methods fall short of operational requirements. This research explored a new approach for determining snow depth using Ku-band multi-pass (monostatic) airborne interferometric synthetic aperture radar (InSAR). A perturbation method that isolated and compared high frequency terrain phase to elevation was used to generate Snow-Off and Snow-On DEMs from the InSAR phase data. Differencing the InSAR DEMs determined elevation change caused by accumulated snow. Comparison of InSAR snow depths to manual snow depth measurements indicated average InSAR snow depth errors of -8cm, 95cm, -49cm, 176cm, 87cm, and 42cm for six SAR pairs. The source of these errors appears to be mostly related to uncorrected slope and tilt in fitted low frequency planes. Results show that this technique has promise but accuracy could be substantially improved by the use of bistatic SAR systems, which would allow for more stable and measurable interferometric baselines.

9077-29, Session 7

Superpixel segmentation using multiple SAR image products

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To categorize terrains and structures in SAR imagery, we first segment the SAR image into homogeneous regions. We compare two segmentation/superpixel algorithms using multiple high-resolution single-polarization SAR products. Speckle produced in coherent SAR image formation can complicate superpixel extraction. Other researchers [Xia13] have introduced a modified pixel similarity measure to discount SAR speckle. In contrast, we exploit SAR image products preprocessed to reduce speckle, which readily facilitate superpixel extraction. These products include sub-aperture multilook (ML) and a smoothed version of interferometric height (IF-H). We have applied the superpixel algorithms, Quickshift [Ved08] and Simple Linear Iterative Clustering [Ach10], to these SAR image products. We compare performance for segmentations derived from both single and dual SAR product inputs using two research-standard segmentation quality measures, undersegmentation error and boundary recall [Lev09], on the match between superpixels and hand-segmented ground truth. We also introduce superpixel purity as a new segmentation quality measure. We discuss issues with scaling intensity values for both single- and dual-input segmentation. Results of this quality analysis determine the best input/algorithm/parameter set for SAR imagery. Applying superpixel segmentation to ML and IF-H images yields superpixels tailored to SAR regions-of-interest, which can reduce image complexity, enhance estimation of statistical features and improve categorization of structures and terrain. These superpixel segmentation algorithms are also applicable to multiple-polarization SAR imagery.

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9077-30, Session 7

Detection and tracking of personnel using a high-speed 94 GHz surveillance radar

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Security screening in crowded places, with the aim of identifying individuals likely to be carrying threat items, is an active area of research. Such a non-compliant scenario requires a stand-off sensor with wide total field of regard in order to cover a usefully large area, high spatial resolution in order to resolve individual people, and high temporal update rate in order to be able to cope with the rapidly changing dynamics of crowds.

We will report on work undertaken by the University of St Andrews in conjunction with the UK Home Office to assess the capability of a high speed 94 GHz surveillance radar with respect to this requirement. The NIRAD radar has a low phase noise, heterodyne FMCW architecture and scans a pencil beam through 360° of azimuth at frame rates of up to 10 Hz. The sub-degree beamwidth and 25 cm range bins yield high resolution plan position indicator (PPI) images of scenes over ranges from tens to hundreds of metres.

The radar imagery is acquired at sufficiently high frame rate to be able to follow people walking or running around the scene. We will present details of how people are detected and tracked in the scene so that their radar cross section images can be analysed to reveal signatures which may indicate the presence of a carried threat item.

9077-31, Session 7

Design considerations for quantum radar implementation

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Quantum Radar provides a means to drastically increase the sensitivity of standard, "classical" radar systems. Targets that would be invisible using standard radar technology, such as stealth aircrafts and weaponry, are rendered completely visible when they are viewed using a quantum radar.

A fully robust quantum radar will utilize many quantum effects to ascertain information about the target. Single photon transmission and detection is a core component in its fundamental design. The radar system will incorporate entangled photons and classical electromagnetic waves at multiple frequencies. The system will also be able to measure multiple properties of the return photons such as momentum and polarization to obtain information about the target in question.

Using single photon beams instead of a full out classical electromagnetic wave changes the radar cross section of the target in question. The radar cross section concept itself must be redefined to fit the quantum nature that it utilizes. Using these quantum phenomena, the radar can theoretically approach the Heisenberg limit under ideal conditions.

The radar itself will be electronically controlled. The computer must be able to change frequencies, and number of photons on the fly for a variety of different targets. Using entangled beams with different number of photons changes the resolution of the radar at different ranges. Different frequencies also change the resolution at different ranges. The proposed implementation must be able to dynamically aggregate and fuse classical and quantum radar information to produce the most reliable localization of the target.

The paper will discuss several considerations required to design and implement a quantum radar system.

9077-32, Session 7

Stepped-frequency nonlinear radar simulation

Gregory J. Mazzaro, The Citadel (United States); Kyle A. Gallagher, The Pennsylvania State Univ. (United States); Anthony F. Martone, U.S. Army Research Lab. (United States); Ram M. Narayanan, The Pennsylvania State Univ. (United States)

The U.S. Army Research Laboratory is evaluating stepped-frequency radar (SFR) for the detection of RF electronics. This form of ultra-wideband (UWB) radar simultaneously provides high range resolution for low instantaneous bandwidth, at the cost of relatively long computation time. Unfortunately, even if computation time is virtually unlimited, RF electronic targets, such as man-portable electronics, cannot be detected by traditional linear SFR because the radar cross section is much smaller than that of nearby clutter.

One technology that is capable of separating RF electronic targets from naturally-occurring clutter is nonlinear radar. For electromagnetically nonlinear electronics, some of the radar waves that reflect from the target oscillate at frequencies different from those transmitted to the target. Reception of frequencies that are not part of the original transmission distinguishes the received signal from a linear return produced by clutter and indicates the presence of electronics.

Presented in this paper is a combination of the stepped-frequency UWB concept with nonlinear detection: nonlinear stepped-frequency radar. Its transmitter, like traditional linear SFR, steps through frequencies one at a time to achieve high range resolution. Its receiver, unlike traditional linear SFR, captures a harmonic of each transmitted frequency to achieve high clutter rejection. By stepping the transmit frequency with known amplitude and phase across an ultra-wide bandwidth and recording the amplitude and phase of the harmonic return signal, a nonlinear frequency response of the radar environment is constructed. An inverse Fourier Transform of this nonlinear frequency response reveals the range to the nonlinear target within that environment. The nonlinear stepped-frequency radar concept is validated in simulation and demonstrated experimentally using a log-periodic antenna and a consumer-electronic target.

9077-33, Session 8

Medical radar considerations for detecting Crohn's disease

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According to the National Digestive Diseases Information Clearinghouse (NDDIC), Crohn's disease is a disorder that causes inflammation and associated complications along any portion of the digestive tract. Over the years, numerous radiological and endoscopic methods as well as the use of ultrasound has been developed to examine and diagnose inflammatory bowel diseases such as Crohn's disease. While such techniques have much merit, a novel medical solution that is robust, non-invasive and inexpensive is proffered. Reflections from electromagnetic signals transmitted by a radar allow for not only range (or extent) information but also spectral analysis of a given target of interest. In particular, the radar cross-section (RCS) of an object measures how detectable the electromagnetic return energy of such an object is to the radar. In this paper, we investigate how disparities in the dielectric properties (e.g. relative permittivity) of diseased and non-diseased sections of the intestines can aid in the detection of Crohn's disease that is often characterized by a distinct pattern of inflammation. Additionally, frequency content-related information and RCS measurements from XFDTD simulations using a simple 3D model of the intestines are discussed. Finally, an ultra-wide band radar system architecture using diverse waveforms is proposed to detect and monitor Crohn's disease. This radar design is evaluated and compared to similar existing medical monitoring devices.

9077-34, Session 8

Development of wearable microwave bladder monitor for the management and treatment of urinary incontinence

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Urinary incontinence is defined as the inability to stop the flow of urine from the bladder. In the US alone, the annual societal cost of incontinence-related care is estimated at 12.6 billion dollars. Clinicians agree that those suffering from urinary incontinence would greatly benefit from a wearable system that could continually monitor the bladder, providing feedback to the patient on the volume of urine in the bladder. While existing ultrasound-based solutions are highly accurate, they are severely limited by form factor, battery size, cost and ease of use. In this study the authors propose an alternative bladder-state sensing system, based on Ultra Wideband (UWB) radar.

As part of an initial proof-of-concept, the authors developed one of the first dielectrically and anatomically-representative Finite Difference Time Domain pelvis models. These models (one male and one female) are derived from Magnetic Resonance Images provided by the IT'IS Foundation. These IT'IS models provide the foundation upon which an anatomically plausible bladder growth model is built. The authors employ accurate multi-pole Debye models to simulate the dielectric properties for each of the pelvic tissues. Two-dimensional FDTD simulations are completed for a range of bladder volumes.

Relevant features are extracted from the FDTD-derived signals using Principle Component Analysis and then classified using a K-Nearest-Neighbor and Support Vector Machine algorithms (incorporating the Leave-one-out cross-validation approach). Additionally the authors investigate the effects of signal fidelity, noise and antenna movement relative to the target as sources of error. The results of this initial study provide strong motivation for further research into this timely application, in the context of an ageing population.

9077-35, Session 8

Development of anatomically and dielectrically accurate breast phantoms for microwave breast imaging applications

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Breast cancer is one of the most common cancers in women. In the United States alone, it accounts for 31% of new cancer cases, and is second only to lung cancer as the leading cause of deaths in American women. More than 184,000 new cases of breast cancer are diagnosed each year resulting in approximately 41,000 deaths. Early detection and intervention is one of the most significant factors in improving the survival rates and quality of life experienced by breast cancer sufferers, since this is the time when treatment is most effective.

One of the most promising breast imaging modalities is microwave imaging. The physical basis of active microwave imaging is the dielectric contrast between normal and malignant breast tissue that exists at microwave frequencies. The dielectric contrast is due to the increased water content present in the cancerous tissue. Microwave imaging is non-ionizing, does not require breast compression, is less invasive than X-ray mammography, and is potentially lower cost.

While several prototype microwave breast imaging systems are currently in various stages of development, the design and fabrication of anatomically and dielectrically representative breast phantoms to evaluate these systems is often problematic. While some existing phantoms are composed of dielectrically representative materials, they rarely accurately represent the shape and size of a typical breast. Conversely, several phantoms have been developed to accurately model the shape of the human breast, but have inappropriate dielectric properties. This study will briefly review existing phantoms before describing the development of a more accurate and practical breast phantom for the evaluation of microwave breast imaging systems.

9077-36, Session 8

Estimation of respiratory rhythm during night sleep using a bio-radar

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One of the most challenging fields of biomedical engineering is development of devices for long-term home vital signs monitoring. In particular, non-contact bio-radiolocation (BRL) monitoring of respiratory rhythm during sleep is of high interest.

BRL is a modern remote sensing technique that allows performing non-contact living objects vital signs monitoring (even behind optically opaque obstacles) on the base of analysis of specific biometric modulation of the reflected radar signal due to oscillatory movements of human limbs and organs (heart beats, respiration movements, etc.).

The experimental data are collected in the Sleep Laboratory of Almazov Federal Heart, Blood and Endocrinology Centre. In total 5 subjects undergo the study up to the moment. The full-night simultaneous respiratory inductance plethysmography (RIP) and BRL records were collected. The internal clock of BRL and RIP systems were synchronized for further verification. A multi-frequency bio-radar with step frequency modulation designed at the Remote Sensing Laboratory (Bauman Moscow State Technical University) was applied. It has 8 operating frequencies ranging from 3.6 to 4.0 GHz.

Obtained data were used for the evaluation of correlation between BRL and RIP respiration rate estimates. Calculated Pearson's correlation coefficient of 0.88 indicates a strong correlation for the data rows. This study shows that BRL method can be used for estimation of respiratory rhythm during full night.

9077-37, Session 8

FDTD modelling of holographic radar application in detection of breast tumors

Irina Alborova, Lesya Anishchenko, Bauman Moscow State Technical Univ. (Russian Federation)

The aim of the study is to determine the possibilities for the use of holographic radar for imaging of breast tumors. In the work the software XFDTD was used, which is designed for the numerical solution of electromagnetic problems using the Finite-Difference Time-Domain Method.

The simulation was performed using three probing frequencies 4, 7 and 15 GHz. The fragment of a breast was modeled as a parallelepiped with dimensions 200x200x100mm. It is mimicking the normal tissue of the breast, with the inclusion of a ball - malignant neoplasm of breast tissue. The size and height of the inclusion has been varied. Frequency dispersion of normal and malignant tissues dielectric properties (conductivity and permittivity) was taken into account.

By using the results obtained with the help of FDTD modeling following conclusions could be made. As expected from theoretical considerations it is preferred to use lower-frequency probing signal, namely, 4GHz, which can detect the inclusion of 5 mm diameter up to a depth of 10 mm. While using of probing signals of 7 and 15 GHz the depth limit of detection inclusion is not more than 8 mm, which is caused by the high attenuation in a medium. However, their usage is preferred because of higher resolution. In the further it is planned to develop an algorithm that allows subtracting from the received signal the signal reflected from the surface layer of the model, which would increase the depth limit for inclusion detecting.

9077-38, Session 8

Comparison between UWB and CW radar sensors for breath activity monitoring

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Remote monitoring of breath activity can be performed by using both ultra wideband (UWB) and continuous wave (CW) radar sensors. UWB radars have been initially developed in hybrid technology [1], while recently some integrated realizations have been proposed [2]. CW radars can be implemented both with hardware and software solutions [3]. In this paper three radar sensors will be compared in order to evaluate their ability in detecting breath activity of a subject placed at various distances from the radar antenna. In particular, a CMOS technology UWB radar developed at the University of Oslo (Uni-Oslo UWB, based on the swept threshold coding technique [2], a hybrid UWB radar developed at the University of Rome (Uni-Rome UWB, based on the range gating technique [4], and a CW radar based on the synchronous detection technique developed at the same University (Uni-Rome CW) have been tested. The radar ability in resolving small target movements has been evaluated by using a copper plate (30 cm ? 45 cm) oscillating forward and backward between two posts. In a series of experiments the distance between the two posts has been varied between 1 mm and 20 mm and the distance between the posts and the antenna between 10 and 300 cm. The Uni-Oslo UWB radar was able to detect a 10 mm oscillation up to a distance of 3 m, the Uni-Rome UWB revealed a 1 mm oscillation up to a distance of 1 m, and the Uni-Rome CW detected a 1 mm movement up to 2 m.

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9077-39, Session 8

Fall detection and classifications based on time-scale radar signal characteristics

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Falls represent the leading cause of fatal and nonfatal injuries among older adults and yield high medical costs. The importance of fall detection is even increasing as the old-age dependency ratio, which is defined as the ratio of population aged 65 and above to the population aged between 20 and 64, is expect to further increase significantly in the next a few decades. Timely and accurate fall detection enables immediate response and renders proper care to be possible. Among a number of techniques that are considered for this purpose, radar is particularly effective because it is non-intrusive and can detect human motions in all types of environments, penetrate walls and fabrics, preserve privacy, and is insensitive to lighting conditions. In this paper, we use the micro-Doppler features of narrowband radar signals corresponding to human body motions and gait to detect falls. Unlike human gait, which is rich in resolvable micro-Doppler components, the fall Doppler radar signature shows power concentrations over extended regions in the time-frequency domain. That is, the motions of the torso and different limbs during the fall appear intertwined and form contiguous clusters when viewed by spectrograms. In this case, features extracted in the time-frequency domain may not be sufficient to detect and properly classify the different types of falls or distinguish their signatures from those associated with sitting, standing, or picking an item from the floor. In this paper, motivated by the aperiodic transient nature of fall signals, we perform detection and classification using time-scale features. Further, we combine features in both time-frequency spectrograms and time-scale scalograms for improved detection and classifications performance.

9077-55, Session Posters-Tuesday

Some comments on performance requirements for DMTI radar

Armin W. Doerry, Douglas L. Bickel, Ann M. Raynal, Sandia National Labs. (United States)

In recent years, a new class of Moving Target Indicator (MTI) radars has emerged, namely those whose mission included detecting moving people, or "dismounts." This new mode is frequently termed Dismount-MTI, or DMTI. Obviously, detecting people is a harder problem than detecting moving vehicles, necessitating different specifications for performance and hardware quality. Herein we discuss some performance requirements typical of successful DMTI radar modes and systems.

9077-56, Session Posters-Tuesday

Backprojection for GMTI processing

Armin W. Doerry, Sandia National Labs. (United States)

Backprojection has long been applied to SAR image formation. It has equal utility in forming the range-velocity maps for Ground Moving Target Indicator (GMTI) radar processing. In particular, it overcomes the problem of targets migrating through range resolution cells.

9077-57, Session Posters-Tuesday

Correcting radar range measurements for atmospheric propagation effects

Armin W. Doerry, Sandia National Labs. (United States)

A fundamental relationship that is the foundation for all radar is that a target's range is proportional to an echo delay time. The actual relationship requires knowledge of the velocity of propagation of the signal whose echo delay time is measured. A typical assumption for radar ranging is to use free-space velocity of propagation. However, atmospheric dielectric properties yield a measurably slower velocity of propagation that is a function of temperature, atmospheric pressure, and especially humidity. This results in range measurement errors. A simplified model is developed to estimate the error in range measurements for airborne ground-surveillance radars.

9077-58, Session Posters-Tuesday

Digital synthesis of linear-FM chirp waveforms: comments on performance and enhancements

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The advent of high-speed, large, gate-count Field Programmable Gate Array (FPGA) components facilitates the implementation of high-performance parametric digital waveform generators for radar applications. One such waveform is the popular Linear-FM chirp. The state-of-the-art allows us to

generate high-fidelity, precision, wideband Linear-FM chirp waveforms with relative ease, and furthermore enhance these waveforms with a number of features, including spectral notches, phase equalization, compound pulses, and more. Design equations are presented, as well as a number of feature enhancements.

9077-59, Session Posters-Tuesday

A novel approach in automatic estimation of rats loco-motor activity

Lesya Anishchenko, Sergey I. Ivashov, Igor Vasiliev, Bauman Moscow State Technical Univ. (Russian Federation)

Laboratory rats are now one of the most common types of animal models in pharmacology and zoo-psychology. At present, the estimation of animal loco-motor activity during the tests is usually made by using specially designed video tracking systems, e.g. Ethovision. The main disadvantages of such systems are the large volume of recorded information and high complexity of the image processing algorithms, which are used.

There are other devices for automated estimation of loco-motor activity parameters of laboratory animals. Some of them contain pressure sensors, optical sensors, receiving and transmitting antennas, mounted in the floor or walls of the cage, which allow estimating the movement of the animal. The main drawback of all these devices is the complexity of manufacturing cells in which the animal is placed during the experiment, and the fact that the devices are designed for a certain kind of animal. That is why quite often loco-motor activity of animals is estimated by the researcher visually.

Bioradars, which is radars for remote estimation of biological objects vital signs, may also be applied for monitoring animals movements. The main advantage of radar usage in this area of application is that a specially designed cell is not needed; it is the possible to do integral evaluation of rat loco-motor activity automatically during prolonged time period (days or weeks). The method can be used with a plastic container, in which the animals usually are housed in laboratories. However, special algorithms for correct distinguishing of different types of movements are still needed. There is another problem: power flux density of reflected signal near radar receiving antenna is inversely proportional to a range to the object of degree four. That is why power of the signal, reflected from an animal and received by bio-radar, depends greatly on the distance between antennas block and animal. Because of this fact correct estimation of rat movement activity becomes challenging task. To make power of the received signal indifferent to location of an animal inside the box it was proposed to use corner reflector, which can be formed by covering two walls and the flour of the box with metal coat. A feasibility study of such approach was made by the experiments, during which bio-radar BioRASCAN-14 was used. It operates at frequency range of 13-14 GHz and uses step-frequency modulated signal. The experimental results showed that usage of a corner reflector eliminates the dependence of received bio-radar signal power level from the distance between animal and antennas block. Furthermore algorithm proposed in was applied for processing of the same experimental data set. In this algorithm the amplitude of the received signal spectrum is used for different types of animal movements distinguishing. It was found that usage of a corner reflector significantly increases the accuracy of the algorithm in recognition of movement types.

9077-60, Session Posters-Tuesday

Application of step-frequency radars in medicine

Lesya Anishchenko, Maksim Alekhin, Alexander Tataraidze, Sergey I. Ivashov, Bauman Moscow State Technical Univ. (Russian Federation); Francesco Soldovieri, Istituto per il Rilevamento Elettromagnetico dell'Ambiente (Italy); Alexander S. Bugaev, Bauman Moscow State Technical Univ. (Russian Federation)

Bioradiolocation is a method for detection and diagnostic of biological objects, even behind optically opaque obstacles, by means of radar. It is based on the reflected signal modulation by movement of the body surface and internals. Objects in the human's body, subjected to periodic fluctuations are cardiac muscle and lungs. Patient's physical activity and medical state determines the values of these fluctuations. Bioradiolocation may find application in different areas of medicine. At Bauman Moscow State Technical University (BMSTU) method of bioradiolocation has been studied since 2002. Two bioradars with stepped frequency modulated probing signals of ranges 3.6-4.0 and 13.6-14.0 GHz were designed. A study of their usage effectiveness in different medical applications (somnology, zoo-psychology) was carried out. With the help of the bioradars designed at BMSTU wide variety of experiments was carried out. The bioradar operating on 3.6-4.0 GHz was used for crewmembers sleep monitoring during the international experiment MARS-500 (simulation of prolonged isolation during a manned flight to Mars), which was conducted in Institute for Biomedical Problems of Russian Academy of Sciences during 2010-2011. The processing of experimental data revealed the individual characteristics of sleep latency and sleeping of crew members. Some of them has longer period of falling asleep and more restless sleep, others on the contrary fall asleep faster and have more calm and regular breathing pattern during sleep time. For none of the crewmembers any clinically significant sleep disordered breathing episodes were registered, however single episodes of obstructive apnea and hypopnea patterns in bioradar signals were detected, which is normal for practically healthy people. At present on the base of Almazov Federal Heart, Blood and Endocrinology Centre bioradar assisted experiments are conducted, during which bioradar data recorded simultaneously with full-night polysomnograms. These experimental data are planed to be used for studying the possibility to distinguish REM and non-REM sleep only by breathing pattern recorded by bioradar without applying any additional contact sensors.

9077-61, Session Posters-Tuesday

Distortion effects in a switch array UWB radar for time-lapse imaging of human heartbeats

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Cardiovascular diseases (CVD) are a major cause of deaths all over the world. Microwave radar can be a new sensor for heart diagnostics and monitoring in modern healthcare that aids early detection of CVD symptoms.

In this paper, measurements from a switch array radar system are presented. This is an UWB system working below 3 GHz that does time-lapse imaging of the beating heart inside the human body. The antenna is an array of eight fat dipole elements. With a RF switch system, every possible sequence of transmit/receive element pairs can be selected to build a radar image from the recordings. To make the radar waves penetrate the human tissue the antenna array is placed in contact with the body. Removal of direct signal leakage through the antennas and body surface are done by high-pass filtering of the data prior to image processing. To analyze the results, measurements of moving spheres in air and simulations are carried out. We see that removal of direct signal introduces amplitude distortion of the images. In addition the effect of small target motion between the collections of data from the individual elements is analyzed. With low PRF this motion will distort the image. By using data from real measurements of heart motion as in the simulations, we analyze how PRF and antenna geometry influence this distortion for heartbeat measurements. Finally the results from the simulations are compared to real measurements of the heart, and means to limit the distortion effects are suggested.

9077-62, Session Posters-Tuesday

Regularized Burg algorithm for small sample-size space-time adaptive processing

Bhashyam Balaji, Defence Research and Development Canada (Canada); Alexis Decurninge, Frederic Barbaresco, Thales Air Systems S.A. (France)

Space-time adaptive processing is an essential component of modern airborne radars with ground-moving target indication capability. An essential requirement for STAP is to estimate the clairvoyant covariance matrix. The standard approach is to use the sample covariance matrix, which is also the maximum-likelihood estimator. The resulting inversion based algorithm is the well-known sample matrix inversion (SMI) algorithm.

However, the SMI algorithm performance is far from optimal. In particular, the loaded sample matrix inversion (LSMI) algorithm, obtained by an ad-hoc addition of a load, is well-known to perform significantly better than the SMI, especially for larger spatio-temporal arrays. An improved performance is also obtained using the projection class of algorithms. This leads one to consider if even better algorithms are possible, and the source of improved algorithms.

The fundamental reason that the SMI is not optimal is that the natural mathematical object for studying covariance matrices is the Riemannian geometry of symmetric cones. The symmetric cone is not a vector space. The flat metric defined geodesic used ubiquitously in signal processing preserves the symmetric positive-definite (SPD) character, i.e., the set of SPD matrices is convex. However, the vector space assumption results in a degraded algorithm. Moreover, the set of SPD matrices with flat metric is not a geodesically complete space.

In previous work it was shown that the Riemannian mean computed using the Karcher barycenter led to a vastly improved performance when the number of clutter samples was small. However, it still had some ad-hoc component, in that it started the iterative Karcher barycenter algorithm with the LSMI estimate.

In this paper, the regularized Burg algorithm , which is based on Bayesian spectral analysis with a frequency domain prior constraint, is used instead. Unlike the previous algorithms, it is completely self-contained in that it does not use the LSMI estimate as the initial condition for the Karcher barycenter algorithm for estimating the covariance matrix. The algorithm is tested with homogeneous and heterogeneous data. Substantial gains over SMI and LSMI are observed when the sample size is small.

9077-63, Session Posters-Tuesday

Radar measurements of moving objects around corners in a realistic scene

Tommy Johansson, Anders Örbom, Ain Sume, Jonas Rahm, Stefan L. Nilsson, Magnus Herberthson, Magnus Gustafsson, Åsa Andersson, Swedish Defence Research Agency (Sweden)

In urban warfare or for surveillance purposes, having a stand-off radar system with the capability of seeing behind corners would be of great importance. The possibility of detecting moving people and objects in the shadow region of a street corner using diffraction and multipath propagation of radar waves has previously been demonstrated in experimental set-ups. In this study we investigate detection of movements in a realistic scene.

The measurements were made using a radar operating at X-band (9,95-10,05 GHz) in a stepped-frequency mode. The moving objects in the measurements are a person walking (at different speeds), riding a bicycle and driving a car, two persons walking and driving two cars. In these experiments a semi-monostatic single receiver-transmitter radar system was used as a data collector. All detections were made after Doppler filtering, using coherent subtraction between different frequency sweeps. An adaptive detection threshold has been applied and the detections can be shown in range vs. time plots, where the movement of the object can been seen as detection tracks.

Detections of movements are made fairly easily. We can identify target returns after one and two wall reflections. We did not try to exploit diffraction in these measurements. The background is generally well suppressed. Two persons moving in the scene can be separated in a range vs. time plot, when allowed by the range resolution.

The results are promising with low false alarm rates. Future work will address positioning and micro-Doppler analysis of the measurements.

9077-64, Session Posters-Tuesday

Investigations of probabilistic data association class of multiple target tracking algorithms for airborne ground moving target indication radars

Bhashyam Balaji, Defence Research and Development Canada (Canada); Kai Wang, MDA Systems Ltd. (Canada)

The problem of automatic track formation and maintenance in the presence of clutter and false alarms is a particularly challenging problem for airborne ground moving target indication (GMTI) radars, due to the spread in clutter Doppler caused by platform motion. In order to be able to detect and track slow ground moving targets, it is essential to cancel clutter adaptively using techniques such as space-time adaptive processing (STAP). This is based on combining the received signals from multiples apertures and pulses, and performing an adaptive estimation of the clutter covariance matrix. STAP enables cancellation of clutter down to the noise level, enabling detection of slow ground-moving targets.

The outputs from STAP include parameter estimates, that are the inputs of a multi-target tracker (MTT). The problem of MTT is to automatically form and maintain tracks of multiple, time-varying number of targets. While the extended Kalman filter (and variants) is often adequate for the filtering component for GMTI applications, the MTT is made challenging due to measurement origin uncertainty. The contributing factors to the data association problem include low SNR, false alarms due to inadequate clutter cancellations, as well as the presence of multiple targets in the vicinity of the target of interest.

There are several approaches to tackling this, that have been investigated in the literature. A particularly popular class of algorithms is based on the probabilistic data association (PDA), which approximates the conditional probability density by a uni-modal Gaussian probability density function, by virtue of its simplicity and ease of implementation. As a result, it is found in several operational systems.

In this paper, we will investigate a few variants of the PDA. In particular, we will start by considering the independent PDA, where the initiated tracks are evolved independently. In contrast, the joint probabilistic data association (JPDA) algorithm better tackles the problem of persistent interference---where measurements from one target can fall in the validation region of a neighbouring target. A further variation is to include target existence probability for each track, and the PDA and JPDA variants are termed the integrated PDA (IPDA) and joint integrated PDA (JIPDA) respectively. We compare the performance of these algorithms with simulated as real data.

9077-65, Session Posters-Tuesday

Power-line characterization from an airborne data collection with a millimeter-wave radar

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Enhancing the operational safety of small, maneuverable rotorcraft has been a critical consideration in the development of next generation situational awareness sensor suites. From landing assistance to target detection and obstacle avoidance, millimeter wave radars have become the leading candidate in this area due to their ability to operate in degraded visual environments, whether it be weather, induced debris, or night conditions that must be dealt with. Power lines pose arguably the largest safety risk due to their difficulty in detection and proper identification to support avoidance maneuvering, where even under perfect conditions they can be nearly invisible to the naked eye. The backscatter phenomenology from braided power lines has been well-studied and formulated in previous literature, albeit mainly in well controlled laboratory settings. Subsequently, the ability to simply detect power lines at operational distances up to around 2 km has been demonstrated. In this work, an analysis is performed on the measureable characteristics of power lines captured in a representative operational environment for helicopters. The test location included a diverse set of power line configurations with surrounding ground and tower clutter, representing a true scenario. A radiometrically calibrated w-band real-beam FMCW sensor allows the study and estimation of target RCS, and evaluation of results against the developed theory. All analysis is performed on dynamically captured data from a helicopter, where platform dynamics and system stability also play a significant role in a processed result. Results from this work will aid the effective development of next generation situational awareness systems.

9077-40, Session 9

Performance bounds on micro-Doppler estimation and adaptive waveform design using OFDM signals

Satyabrata Sen, Jacob Barhen, Charles W. Glover, Oak Ridge National Lab. (United States)

We analyze the performance of a wideband orthogonal frequency division multiplexing (OFDM) signal in estimating the micro-Doppler frequency of a target having multiple rotating scatterers (e.g., rotor blades of a helicopter, propellers of a submarine). The presence of rotating scatterers introduces Doppler frequency modulation in the received signal by generating sidebands about the transmitted frequencies. This is called the micro-Doppler Effect (mDE). The use of a frequency-diverse OFDM signal in this context enables us to independently analyze the mDE characteristics with respect to a set of orthogonal subcarrier frequencies. Therefore, to characterize the accuracy of micro-Doppler frequency estimation, we compute the Cramer-Rao Bound (CRB) on the angular-velocity estimate of the target while considering the scatterer responses as deterministic but unknown nuisance parameters. Additionally, to improve the accuracy of the estimation procedure, we formulate and solve an optimization problem by minimizing the CRB on the angular-velocity estimate with respect to the transmitting OFDM spectral coefficients. We present several numerical examples to demonstrate the CRB variations at different values of the signal-to-noise ratio (SNR) and the number of OFDM subcarriers. The CRB values not only decrease with the increase in the SNR values, but also reduce as we increase the number of subcarriers implying the significance of frequency-diverse OFDM waveforms. The improvement in estimation accuracy due to the adaptive waveform design is also numerically analyzed. Interestingly, we find that the relative decrease in the CRBs on the angular-velocity estimate is more pronounced for larger number of OFDM subcarriers.

9077-41, Session 9

Characterization of micro-Doppler radar signature of commercial wind turbines

Fanxing Kong, Yan Zhang, Robert Palmer, The Univ. of Oklahoma (United States)

With the rapid growth of wind power industry, many large commercial wind turbines have been built. These extremely large man-made structures are reported to have negative impact on nearby radars due to complex scattering mechanisms. This phenomenon is usually referred to as the radar Wind Turbine Clutter (WTC), which is a general description of various effects wind turbines may have on radar sensing process, including the isolated clutter, multi-path clutter and partial beam blockage, etc.

A typical wind turbine is composed of stationary parts (foundation and tower), slow moving parts (nacelle, hub and nose cone) and fast moving parts (rotor blades). Due to its large size, the speed at the tip of the blade can reach 80 m/s, beyond the aliasing velocity of most ground-based operational radars. As a result, extremely complicated mico-Doppler spectra have been observed. And conventional ground clutter filter techniques have failed to mitigate the non-stationary components in the frequency domain.

Rotation of the blades is a micro-motion as the overall wind turbine structure stays at the same location. The time-evolving spectrum associated with the blade rotation is important in characterizing radar WTC. This paper will present some latest findings from our studies for characterizing the Micro-Doppler radar signatures of wind turbine through radar measurement, scaled model measurement and electromagnetic propagation and scattering modeling. These characterizations can be potentially useful in detection and identification of wind turbine interference, as well as further mitigation of the clutter impacts.

9077-42, Session 9

Micro-Doppler classification of rider and riderless horses

David Tahmoush, U.S. Army Research Lab. (United States)

Micro-range Micro-Doppler can be used to isolate particular parts of the radar signature, and in this case we demonstrate the differences in the signature between a walking horse versus a walking horse with a rider.

9077-43, Session 9

Effect of wind turbine micro-Doppler on SAR and GMTI signatures

Rajan Bhalla, Leidos (United States); Hao Ling, The Univ. of Texas at Austin (United States)

In this work, we perform a modeling study to examine the interference effect of microDopplers caused by offshore wind farms on airborne sensors operating in the synthetic aperture radar (SAR) or ground moving target indicator (GMTI) mode. The modeling is carried out in two steps. In the first step, the dynamic signature of an individual wind turbine is simulated using the high-frequency electromagnetic software Xpatch. This entails generating snapshot CAD models capturing the turbine blade rotation. These models are then used to carry out the radar signature computation and form range profiles for the various CAD instantiations. In the second step, the sensor motion is used in conjunction with the wind turbine signature to form a time history. The radar data from an entire wind farm is obtained by neglecting interactions between turbines and summing the responses from individual turbines. The simulated radar data are then post processed to form SAR images or GMTI range-Doppler chips. A wind farm comprising 4 x 4 turbines is modeled at X-band. The SAR simulations show that the dynamic signatures from rotating turbine blades cause cross-range artifacts in the resulting SAR images. These artifacts extend along the cross-range dimension and can be seen beyond the physical location of the wind farm. The GMTI simulations show that the dynamic signatures from rotating turbine blades cause Doppler artifacts in the resulting range-Doppler chips. The corruption in the range-Doppler chips is limited to the Doppler extent from the turbine blades, and is bursty in time. These artifacts can potentially interfere with tracking of boats in coastal waters. Some signal filtering algorithms are tried to reduce the dynamic turbine clutter in both SAR images and GMTI displays. Depending on the filtering parameters, they show varying degree of effectiveness in filtering out the turbine clutter.

9077-44, Session 9

Detection of small UAV helicopters using micro-Doppler

David Tahmoush, U.S. Army Research Lab. (United States)

The detection of small unmanned aerial vehicles (UAVs) using radar can be challenging due to the small radar cross section and the presence of false targets such as birds. We present the initial results of micro-Doppler radar data collected on a small helicopter at G-band and compare the results to previously measured birds. The resulting signature differences can be used to help discriminate small UAVs from naturally occurring moving clutter such as birds.

9077-45, Session 10

Software-defined radar and waveforms for studying micro-Doppler signatures

Baokun Liu, Rachel Chen, Ancortek Inc. (United States)

We have implemented a software defined radar using the open-source GNU Radio toolkit and the Universal software Radio Peripheral (USRP) for studying micro-Doppler signatures of human gaiting and helicopter rotating rotor blades.

In this paper, we first introduce the state of the art of software defined radar: design concepts, advantages, and special consideration for radar micro-Doppler signature studies. Then, we discuss the GNU radio toolkit implemented on a host computer and its various GNU building blocks including waveform generators, modulations, demodulations, mixers, filters, and other signal processing functions. In the software defined micro-Doppler radar, we used the USRP N210 motherboard (including D/A converter, A/D converter, the field programmable gate array, and high-speed Ethernet interfacing) connected to a RF front-end daughterboard to serve as the interface between the RF and the baseband processing. We implemented CW, sawtooth FMCW, triangular FMCW, and other waveforms for studying micro-Doppler, micro-range, and range-Doppler signatures.

Using this software defined micro-Doppler radar, we collected radar data from human gaiting and helicopter rotating rotor blades. Finally, we analyzed our experimental results using CW and FMCW signal waveforms for studying micro-Doppler signatures combined with micro-range signatures and range-Doppler images for characterizing human gaiting and rotor blades rotating.

9077-46, Session 10

Very low-phase noise, coherent 94 GHz radar for micro-Doppler and vibrometry studies

Duncan A. Robertson, Univ. of St. Andrews (United Kingdom); Graham M. Brooker, The Univ. of Sydney (Australia); Patrick D. L. Beasley, QinetiQ Ltd. (United Kingdom)

To reveal target signatures using micro-Doppler and vibrometry techniques requires radars which operate coherently and possess very low phase noise. Performing these measurements at millimetre or sub-millimetre wave frequencies offers higher Doppler sensitivity than microwave radars but presents technological challenges to meet the required level of performance.

Building on work published at DSS 2013 we wish to report on the development and characterisation of a new 94 GHz radar which offers fully coherent operation with very low phase noise. The radar, dubbed T-220, uses separate transmit and receive antennas with fan beam profiles to ensure low transmit-receive leakage and modest elevation coverage whilst maintaining fine azimuth resolution. The signal generation scheme exploits a commercially available direct digital synthesis (DDS) chirp generator which is upconverted onto a microwave stable local oscillator (STALO) prior to frequency multiplication to the carrier frequency. This scheme yields very low phase noise and rapid, contiguous chirps, necessary for Doppler studies and other coherent processing techniques.

We will present results which highlight the effects of the superior phase noise afforded by this system compared with previous work, including micro-Doppler measurements of people and vibrometry measurements of various targets. Additionally, we will present very high dynamic range plan position indicator (PPI) images of scenes which exploit the low phase noise to yield imagery with great fidelity, suitable for many applications including surveillance.

9077-47, Session 10

Comparative of signal processing techniques for micro-Doppler signature extraction with automotive radar systems

Berta Rodriguez Hervas, The Univ. of Texas at El Paso (United States) and Mercedes-Benz Research & Development North America, Inc. (United States); Michael Maile, Mercedes-Benz Research & Development North America, Inc. (United States); Benjamin C. Flores, The Univ. of Texas at El Paso (United States)

During the last years, the automotive industry has experienced an evolution towards more powerful driver assistance systems, leading to enhanced vehicle safety. Those systems include sensors such as cameras and radars, and have demonstrated high efficiency on collision and risk avoidance. Radar systems are particularly relevant, due to their operational robustness under adverse weather or illumination conditions. Our objective is to study different signal processing techniques suitable for extraction of accurate Micro-Doppler signatures of slow moving objects in dense urban environments. For this purpose, we carry out a set of simulations of typical radar detection response on common driving situations, and perform the analysis with several signal processing algorithms, such as Short Time Fourier Transform, Continuous Wavelet Analysis or Kernel based Analysis Methods. To obtain valid results, we take account of factors such as the relative movement between the ego vehicle and target, and the non-stationary nature of the movement. As conclusion, a comparison between the different results obtained is presented. Selection of the appropriate signal processing technique is crucial for the extraction of accurate Micro-Doppler signatures that will lead to the correct result based on the Radar Classifier system.

9077-48, Session 10

Stationary and moving target shadow characteristics in synthetic aperture radar

Ann M. Raynal, Douglas L. Bickel, Armin W. Doerry, Sandia National Labs. (United States)

Shadows in synthetic aperture radar (SAR) imagery are created when a target with height blocks incident radar energy from illuminating the area immediately behind it. Shadows depend on the physical dimensions and mobility of a target, platform and radar imaging parameters, and scene clutter. Target shadows can be important for target detection, location, and tracking or even identification. However, SAR shadows prove difficult to capture as a target or platform moves, since the no-return area may quickly degrade. In this paper, we provide a general formulation of SAR shadow dimensions and intensity for targets with an arbitrary motion.

9077-49, Session 10

Extremely high-frequency micro-Doppler measurements of humans

Charles R. Dietlein, Abigail S. Hedden, U.S. Army Research Lab.

(United States); Jeremy A. Green, Univ. of Maryland, College Park (United States); Jerry L. Silvious, David A. Wikner, U.S. Army Research Lab. (United States)

Operation in the EHF portion of the spectrum—specifically, near the 220 GHz atmospheric window—introduces simultaneous advantages and challenges for radar systems. The advantages include (1) the high available bandwidth, resulting in improved range resolution, (2) the ability to generate video-rate synthetic aperture radar (SAR) imagery from an airborne platform, and (3) the ability to penetrate common atmospheric obscurants such as clouds and dust. The latter two advantages imply that next-generation SAR systems in the EHF band have the potential to supplant existing optical and infrared imaging systems, providing improved safety during landing, and situational awareness in general, for airborne systems operating in poor atmospheric conditions. On the other hand, the present challenges at these frequencies include (1) a lack of compact and reliable high-power transmitters, (2) a gap in knowledge of the scattering properties of natural and artificial surfaces, (3) incomplete understanding of the fully-polarimetric backscatter of rain, and (4) the unknowns of radar cross section (RCS) and micro-Doppler signatures of humans.

We are developing a fully-polarimetric frequency-modulated continuous-wave instrumentation radar to explore the latter three of the aforementioned topics, as part of DARPA's Video-rate SAR (ViSAR) program. The radar is comprised of commercial off-the-shelf components, with the exception of the high-performance orthomode transducers that are custom-built to provide the isolation necessary for measuring the weak cross-polarized return from rain. In this presentation we will describe the radar system and our progress so far, including RCS and micro-Doppler measurements of humans (and a phenomenological description of the results), and monostatic backscatter from surfaces such as asphalt and building materials. Additionally, we will present the experiment configuration we are developing to characterize in situ rain.

9077-50, Session 11

SAR moving target imaging in complex scenes using sparse and low-rank decomposition

Kang-Yu Ni, Shankar R. Rao, HRL Labs., LLC (United States)

We propose a method to image a complex scene with spotlight synthetic aperture radar (SAR) despite the presence of multiple moving targets. Many recent methods use sparsity-based reconstruction coupled with phase error corrections of moving targets to reconstruct stationary scenes. However, these methods rely on the assumption that the scene itself is sparse and thus unfortunately cannot handle realistic SAR scenarios with complex backgrounds consisting of more than just a few point targets.

Our method makes use of sparse and low-rank (SLR) matrix decomposition, an efficient method for decomposing a low-rank matrix and sparse matrix from their sum. For detecting the moving targets and reconstructing the stationary background, SLR uses a convex optimization model that penalizes the nuclear norm of the low rank background structure and the L1 norm of the sparse moving targets.

We propose an L1-norm regularization reconstruction method to form the input data matrix, which is grossly corrupted by the moving targets. Each column of the input matrix is a reconstructed SAR image with measurements from a small number of azimuth angles. The use of the L1-norm regularization and a sparse transform permits us to reconstruct the scene with significantly fewer measurements so that moving targets are approximately stationary.

We demonstrate our SLR-based approach using simulations adapted from the GOTCHA Volumetric SAR data set. These simulations show that SLR can accurately image multiple moving targets with different individual motions in complex scenes where methods that assume a sparse scene would fail.

9077-51, Session 11

Lidar compressive sensing using chaotic waveform

Berenice Verdin, Ricardo von Borries, The Univ. of Texas at El Paso (United States)

Full waveform lidar systems are designed to acquire the complete signal reflected from an illuminated target and they can provide more detailed information about the target than conventional lidar. They demand the acquisition of high volumes of data, but by using a compressive sensing approach it is possible to reduce the data acquisition sampling rate and still recover the full response from the target. The sampling rate reduction can be incorporated in the acquisition hardware to perform sensing of the signal with compression. In this paper, we propose to use a deterministic compressive sensing approach by using a chaotic signal as the sensing matrix. The proposed approach gives the range profile information without the requirement of further processing techniques. For comparison, we used two different types of transmitted signals: chaotic and linear frequency modulated (LFM) signals. Simulations demonstrate that chaotic signals give better results than the LFM signals. By using a chaotic signal we can obtain the impulse response of the target by using less than 20 percent of the samples used with LFM signals.

9077-52, Session 11

Off-grid compressive sensing ultra-wideband radar imaging

Shugao Xia, Delaware State Univ. (United States)

Compressive sensing (CS) schemes have been widely proposed for spatial sparsity of the target space in radar imaging applications to decrease the data acquisition load in practical systems, while also generating high-resolution images. These schemes mainly discretize the continuous target space into grid points and generate a dictionary of model data to form an optimization problem for radar image reconstruction. The choice of the grid for generating the sparsity inducing basis or dictionary is a central point of CS and sparse approximation. However, good sparse recovery performance is based on the assumption that the targets are positioned at the pre-discretized grid locations; otherwise, the performance would significantly degrade. This phenomenon is known as the off-grid problem. This paper investigates ultra-wideband (UWB) radar imaging which incorporates error caused by the off-grid targets. The joint sparse recovery method is proposed for reducing the effect of the grid to locate the off-grid target. Numerical examples demonstrate the robust results with much smaller reconstruction errors using the joint sparse recovery method are obtained for off-grid targets compared to standard sparse reconstruction techniques.

9077-53, Session 11

Wideband aperture array using RF channelizers and massively-parallel digital 2D IIR filterbank

Arindam Sengupta, Arjuna Madanayake, The Univ. of Akron (United States); Roberto Gómez-García, Univ. de Alcalá (Spain); Erik Engeberg, The Univ. of Akron (United States)

Wideband receive-mode beamforming applications in wireless location, electronically-scanned antennas for radar, RF sensing, microwave imaging and wireless communications require digital aperture arrays that offer a relatively constant far-field beam over several octaves of bandwidth. Several beamforming schemes including the well-known true time-delay and the phased array beamformers have been realized using either finite impulse response (FIR) or fast Fourier transform (FFT) digital filter-sum based techniques. These beamforming algorithms offer the desired selectivity at the cost of a high computational complexity and frequency-dependant far-field array patterns. A novel approach to receiver beamforming is the use of massively parallel 2-D infinite impulse response (IIR) fan filterbanks for the synthesis of relatively frequency independent RF beams at an order of magnitude lower multiplier complexity compared to FFT or FIR filter based conventional algorithms. The 2-D IIR filterbanks demand fast digital processing that can support several octaves of RF bandwidth, fast analog-to-digital converters (ADCs) for RF-to-bits type direct conversion of wideband antenna element signals. Fast digital implementation platforms that can realize high-precision recursive filter structures necessary for real-time beamforming, at RF radio bandwidths, are also desired. We propose a novel technique that combines a passive RF channelizer, multi-channel ADC technology, and single-phase massively parallel 2-D IIR digital fan filterbanks, realized at low complexity using FPGA and/or ASIC technology. There exists native support for a larger bandwidth than the maximum clock frequency of the digital implementation technology. We also strive to achieve More-than-Moore throughput by processing a wideband RF signal having content with N-fold (B=N.Fc/2) bandwidth compared to the maximum clock frequency Fc Hz of the digital VLSI platform under consideration. Such increase in bandwidth is achieved without use of polyphase signal processing or time-interleaved ADC methods. That is, all digital processors operate at the same Fc clock frequency without phasing, while wideband operation is achieved by sub-sampling of narrower sub-bands at the the RF channelizer outputs. FPGA based co-simulations and ASIC synthesis results provide compelling evidence of high throughput, and the maximum clock frequency demanded by the design.

9077-54, Session 11

Signal processing techniques for stepped frequency ultra-wideband radar

Lam H. Nguyen, U.S. Army Research Lab. (United States)

The Army Research Laboratory has developed the ground vehicle-based forward-looking Ultra-Wideband (UWB), synthetic aperture radar (SAR) for the detection of concealed targets. Although the impulse-based architecture offers its own advantages, one of the important challenges is that when using this architecture it is very difficult to transmit radar signal with arbitrary bandwidth and shape. This feature is crucial in order for the radar to be compliant with the local frequency authority. In addition, the ability to transmit an arbitrary waveform is an important step for the next generation of smart (cognitive) radar. Therefore, we have decided to design the next generation prototype radar to take advantage of the stepped frequency architecture. The design and building of the radar hardware is underway.

In this paper, we study the radar transmit and acquisition scheme, the trade-offs between SAR image performance and various key radar parameters, and the data reconstruction techniques for radar signals with arbitrary spectrum. This study is conducted to demonstrate performance, provide guidelines for radar design, and serve as a foundation of the signal and image processing stage. The results will be shown using simulated data.

Thursday - Friday 8 –9 May 2014

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9078-1, Session 1

TeraSCREEN: multi-frequency multi-mode Terahertz screening for border checks

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The challenge for any security screening system is to identify potentially harmful objects such as weapons and explosives concealed under clothing. Classical border and security checkpoints are no longer capable of fulfilling the demands of today's ever growing security requirements, especially with respect to the high throughput generally required which entails a high detection rate of threat material and a low false alarm rate. TeraSCREEN proposes to develop an innovative concept of multi-frequency multi-mode Terahertz and millimeter-wave detection with new automatic detection and classification functionalities. The system developed will demonstrate, at a live control point, the safe automatic detection and classification of objects concealed under clothing, whilst respecting privacy and increasing current throughput rates. This innovative screening system will combine multi-frequency, multi-mode images taken by passive and active subsystems which will scan the subjects and obtain complementary spatial and spectral information, thus allowing for automatic threat recognition.

The TeraSCREEN project, which will run from 2013 to 2016, has received funding from the European Community's Seventh Framework Programme under the Security Call.

9078-2, Session 1

Determination of truckload by microwave and millimeter-wave imaging

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The freight transportation service by truck is an extremely growing market all over the world. On the other hand the road traffic infrastructure in most countries is overloaded and is not or could not grow in an appropriate manner. Hence there is a strong demand to optimize the capacity utilization of trucks in order to reduce the volume of truck traffic on the roads. Freight transportation companies are loading their trucks in the daily business not always with the focus on efficient volume utilization. Mostly the loading is done by experience of the forklift operator. Hence there is an interest to estimate the volume distribution of truckload with a fast and stand-off monitoring sensor under common driving conditions. MW or MMW sensors like radars and radiometers can provide a significant benefit to this task due to the penetration capabilities of these wavelengths through thin dielectric walls for example like plastic truck covers. As a very useful side effect such a system can deliver valuable information for security applications, e.g. about illegal transportation attempts, when installed on suitable locations. This paper describes the problem oriented application of DLR's experimental MW radar and MMW radiometer sensors for the estimation of truckload under controlled slow driving conditions of a test truck. Various measurement geometries have been identified and tested by suitable experiments. Conventional load as it is available on transfer stations of freight companies has been used in order to estimate the sensor performances with respect to the intended tasks. It points out that both radar and radiometer approaches have benefits for the intended application. The different ideas and some representative experimental imaging results of both systems are presented.

9078-3, Session 1

Standoff passive video imaging at 350 GHz with 251 superconducting detectors

Daniel T. Becker, National Institute of Standards and Technology (United States); Cale Gentry, Univ. of Colorado (United States); Ilya Smirnov, Univ. of Maryland (United States); James A. Beall, Hsiao-Mei Cho, William D. Duncan, Dale Li, Gene C. Hilton, National Institute of Standards and Technology (United States); Kent D. Irwin, Stanford Univ. (United States); Nicholas G. Paulter Jr., Carl D. Reintsema, Robert E. Schwall, National Institute of Standards and Technology (United States); Peter A. Ade, Carole E. Tucker, Cardiff Univ. (United Kingdom); Simon R. Dicker, Univ. of Pennsylvania (United States); Mark Halpern, The Univ. of British Columbia (Canada)

Millimeter wavelength radiation holds promise for detection of security threats at a distance, including suicide bomb belts and maritime threats in poor weather. The high sensitivity of superconducting Transition-Edge-Sensor (TES) bolometers makes them ideal for passive imaging of thermal signals at millimeter and submillimeter wavelengths. We have built a 350 GHz video-rate imaging system using large-format arrays of feedhorn-coupled TES bolometers. The system operates at a standoff distance of 16-28 m with a spatial resolution of 1 cm (at 16 m). It currently contains one 251-detector sub-array, and will be expanded to contain four sub-arrays for a total of 1004 detectors. The system has been used to take video images which reveal the presence of weapons concealed beneath a shirt in an indoor setting. We will present analysis of these videos, the results of beam mapping and optical efficiency measurements, and progress towards installation of the second 251-detector sub-array.

9078-5, Session 1

Improvements to the design process for a real-time passive millimetre-wave imager to be used for base security and helicopter navigation in degraded visual environments

Rupert N. Anderton, Colin D. Cameron, James G. Burnett, QinetiQ Ltd. (United Kingdom); Jeff J. Guell, The Boeing Co. (United States); Jack Sanders-Reed, Boeing-SVS, Inc. (United States)

This paper discusses the design of an improved passive millimetre wave imaging system intended to be used for base security in degraded visual environments. The discussion starts with the selection of the optimum frequency band. The trade-offs between requirements on detection, recognition and identification ranges and optical aperture are discussed with reference to the Johnson Criteria. It is shown that these requirements also affect image sampling, receiver numbers and noise temperature, frame rate, field of view, focussing requirements and mechanisms, and tolerance budgets. The effect of image quality degradation is evaluated and a single testable metric is derived that best describes the effects of degradation on meeting the requirements. The discussion is extended to tolerance budgeting constraints if significant degradation is to be avoided, including surface roughness, receiver position errors and scan conversion errors.

Although the reflective twist-polarisation imager design proposed is potentially relatively low cost and high performance, there is a significant problem with obscuration of the beam by the receiver array. Methods of modelling this accurately and thus designing for best performance are given.

9078-6, Session 1

Reflectarray design and its element characterization at millimeter wavelengths

Aleksi A. Tamminen, Juha Ala-Laurinaho, Tom F. Gallacher, Antti V. Räisänen, Aalto Univ. School of Science and Technology (Finland)

We present design and simulations of a reconfigurable reflectarray suitable for use as a sub-reflector in a confocal millimeter-wave imaging system. In such an imaging system, the required steering range of the reflectarray is rather limited and high steering resolution is needed. We evaluate the performance of different kind of reflectarray configurations, i.e., phase quantization and feeding field, for the confocal imaging system. A quantized-particle-swarm optimization is applied in order to mitigate the effects of the periodic phase error across the reflectarray. Also, the grating lobes due to discontinuities, e.g. bonding wires, can be suppressed with the optimization algorithm. The reflectarray element is based on microstrip structures, and the reconfigurability is achieved with MEMS-based phase shifters. Both 1- and 2-bit phase quantization is considered.

A reflectarray is characterized in a near-field measurement range. There, the reflection from the individual reflectarray elements is imaged at a distance of the order of a wavelength. Both the realized reflection phase and magnitude of the specular reflection are determined – giving more information on the reflectarray element performance than a beam pattern measurement is capable of. A near-field measurement system is set up and tested at 120 GHz. The lateral resolution and phase measurement accuracy are 0.56λ and ±4°, respectively. A static reflectarray is tested in the measurement system, and the reflection coefficient of the individual elements of it is measured.

9078-7, Session 2

Progress in passive submillimeter-wave video imaging

Erik Heinz, Supracon AG (Germany) and Institut für Photonische Technologien e.V. (Germany); Torsten May, Detlef Born, Gabriel Zieger, Katja Peiselt, Institut für Photonische Technologien e.V. (Germany); Vyacheslav Zakosarenko, Supracon AG (Germany) and Institut für Photonische Technologien e.V. (Germany); Torsten Krause, André Krüger, Marco Schulz, Frank Bauer, Hans-Georg Meyer, Institut für Photonische Technologien e.V. (Germany)

Passive submillimeter-wave scanning has been in the focus of interest as a promising technology for personal security screening for a number of years. In contradiction to established portal-based millimeter-wave scanning techniques it uses quasi-optical imaging and therefore is suitable for stand-off or stealth operation. Possible application scenarios demand sensitive, fast, and flexible high-quality imaging techniques. Considering the low radiometric contrast of indoor scenes in the submillimeter range, this objective calls for a high detector sensitivity that can only be achieved using cooled detectors.

Our approach to this task is a series of passive standoff video cameras for the 350 GHz band using arrays of superconducting transition-edge sensors (TES), reflector optics, and opto-mechanical scanners. These cameras represent an evolving concept and a continuous development since 2007. The TES are operated at temperatures below 1 K, cooled by a closed-cycle cooling system, and coupled to superconducting readout electronics. By this means, background limited photometry (BLIP) mode is achieved providing the maximum possible signal to noise ratio. At video rates, this leads to a pixel NETD well below 1 K.

The latest product of this camera development features a linear array of 128 detectors and a linear scanner capable of 25 Hz frame rate. Using different types of reflector optics, a field of view of 1x2 m^2 and a spatial resolution of 1-2 cm is provided at object distances of about 5-25 m. We present the concept of this camera and give details on system design and performance. Demonstration videos show it's capability for hidden threat detection and illustrate possible application scenarios.

9078-8, Session 2

Passive 670 GHz imaging with uncooled low-noise HEMT amplifiers coupled to zero-bias diodes

Erich N. Grossman, National Institute of Standards and Technology (United States); Xiaobing Mei, Kevin M. Leong, Northrop Grumman Corp. (United States); William R. Deal, Northrop Grumman Aerospace Systems (United States)

We discuss the application of recently developed 670 GHz low-noise amplifiers based on InP HEMTs to passive indoor imaging. Packaged LNAs were integrated with commercial zero-bias diodes, and accurate measurements of system noise-equivalent temperature difference (NETD) made, using blackbody sources. The NETD values are compared with independent prior measurements (Deal et al. 2011) of LNA gain, noise figure, and bandwidth, and with cryogenic bolometer measurements made in the same test conditions. Currently, the LNA gain is not sufficient to render the ZBD noise negligible; measurements are presented that separate the two components. Low-frequency noise measurements are also presented that display the effects of 1/f noise in the ZBD and gain variations in the LNA. The implications of the low-frequency noise are discussed in terms of scanning or beam-steering strategies for an imager based on the LNAs. Raster-scanned, single-pixel images of indoor scenes are presented. They are quantitatively interpreted in terms of NETD, and angular resolution and coupling efficiency of the optics.

9078-9, Session 2

Surface and volumetric backscattering at millimeter-wave and terahertz frequencies

David A. DiGiovanni, Andrew J. Gatesman, Robert H. Giles, Univ. of Massachusetts Lowell (United States); William E. Nixon, National Ground Intelligence Ctr. (United States)

Successful development of remote sensing and communication systems in the terahertz band requires a better understanding of the scattering behavior of various structures. Materials that could be considered homogeneous and smooth at microwave frequencies may begin to display diffuse and volumetric scattering behavior in the terahertz band. The copolarization and cross-polarization backscattering coefficient of several types of metal and dielectric structures were measured in indoor compact radar ranges operating between 0.10 THz and 1.56 THz. These structures consisted of roughened Aluminum plates, homogeneous dielectric surfaces, and inhomogeneous dielectric surfaces. The roughness and inclusions of the measured samples were tailored in order to systematically investigate various scattering effects. Polarimetric backscattering measurements of these materials were collected at incident angles from 15 to 85 degrees. Analysis of the backscatter data supports a better understanding of surface and volumetric scattering behavior of materials in the 0.10 – 1.56 THz region.

9078-10, Session 2

650 GHz bistatic scattering measurements on human skin

Richard A. Chamberlin, Erich N. Grossman, Natalie Mujica-Schwahn, National Institute of Standards and Technology (United States)

Many groups are developing submillimeter cameras that may be used to screen human subjects for improvised explosive devices (IEDs) and other threat items hidden beneath their clothing. In order to interpret submillimeter camera images the scattering properties, specifically the bidirectional reflectance distribution of (BDRF) must be known. This problem is not trivial because surfaces of manmade objects and human skin have features comparable to the wavelength of submillimeter radiation – thus simple, theoretical scattering approximations do not apply. To tackle this problem we built a goniometer instrument to measure the BDRF from skin surfaces of live human subjects illuminated with a 650GHz beam. Skin areas sampled are from the hand, interior of the forearm, abdomen, and back. The beam power density is less than 0.1 mW/cm^2. The 650GHz beam has an approximately Gaussian profile with a FWHM of approximately 1 cm. Instrument characteristics: angular resolution 6deg; noise floor 35dB/sr; dynamic range > 50dB; either S or P polarization; 30deg < bidirectional scattering angle <= 180deg; and, the human scattering target skin area is placed exactly on the goniometer center of rotation. Our results are compared to prior measurements on random, rough surfaces. This new work enables optically (radiometrically) correct models of humans.

9078-11, Session 2

Large distance 3D imaging of hidden objects

Daniel Rozban, Ariel Univ. (Israel); Natan S. Kopeika, Ben-Gurion Univ. of the Negev (Israel); Amir Abramovich III, Ariel Univ. (Israel); Avihai Aharon Akram, Assaf Levanon, Ben-Gurion Univ. of the Negev (Israel)

Imaging systems in millimeter waves are required for applications in medicine, communications, homeland security, and space technology. This is because there is no known ionization hazard for biological tissue, and atmospheric attenuation in this range of the spectrum is low compared to that of infrared and optical rays. The lack of an inexpensive room temperature detector makes it difficult to give a suitable real time implement for the above applications.A 3D MMW imaging system based on chirp radar was studied previously using a scanning imaging system of a single detector. The system presented here proposes toemploy a chirp radar method with Glow Discharge Detector (GDD) Focal Plane Array (FPA of plasma based detectors) using heterodyne detection. The intensity at each pixel in the GDD FPA yields the usual 2D image. The value of the I-F frequency yields the range information at each pixel. This will enable 3D MMW imaging. In this work we experimentally demonstrate the feasibility of implementing an imaging system based on radar principles and FPA of inexpensive detectors. This imaging system is shown to be capable of imaging objects from distances of at least 10 meters.

9078-12, Session 3

Spatially selective mirror for compressive sensing imaging system

Steven T. Griffin, The Univ. of Memphis (United States)

Compressive sensing has been identified as a significant technique to reduce the volume of data collected in sensing applications to a minimum. This is required to ease the power, mass and physical requirements of many systems including imaging applications. Prior art has empirically demonstrated the effectiveness of a spinning disk for reconstruction of TeraHertZ (THZ) images. In these systems, the rotating disk is perforated with transmitting holes slightly larger than the wavelength. Modeling of this system suggests a description based on the non-linear combination of pin-hole lens slightly larger than the THZ wavelength used. Prior empirical data has demonstrated reconstruction artifacts that are associated, in part, with the statistical Probability Density Function (PDF) of the randomly distributed transmission holes in the rotating plate. Empirical demonstration at other wavelengths such as the InfRared (IR) has also been suggested. In this later implementation, the holes will typically be significantly larger than a single wavelength. This document summarizes the statistical requirements for artifact minimization for the previously reported spinning disk system. Particular emphasis is placed on the impact of a wavelength change from TeraHertZ (THZ) to InfRared (IR) wavelengths where the hole's diameter is no longer on the order of the incident wavelength. Analysis indicates that the placement of the rotating axis with respect to the optical axis impacts the non-linearity and preferred statistical distribution.

9078-13, Session 3

Rapid beam steering at mmw and submmw frequencies using an optoelectronic photo-injected Fresnel zone plate

Tom F. Gallacher, Aalto Univ. School of Science and Technology (Finland) and Univ. of St. Andrews (United Kingdom); Rune Søndenå, Institute for Energy Technology (Norway); Duncan A. Robertson, Graham M. Smith, Univ. of St. Andrews (United Kingdom)

Optoelectronic beam steering provides an alternative method for rapid and highly flexible beam steering, with support for applications ranging from microwave through to terahertz frequencies. In particular, the photo-injected Fresnel zone plate antenna (piFZPA) method, wherein a photo-excited Fresnel zone plate plasma creates a dynamic binary lens, offers highly accurate, symmetric, directive and rapid beam control which has the potential to yield low-cost, video rate imagery using no moving parts.

We will present the latest results obtained using our novel piFZPA architecture. In our approach we integrate an OEM digital light projection (DLP) system that enables rapid beam steering up to 32,000 beams per second, when twinned with a suitable semiconductor substrate.

We will discuss the diverse design challenges involved in realizing this approach, which synergises various aspects of optics, semiconductor and terahertz science in a single platform. We will present rapid beam steering results, which will demonstrate highly flexible, symmetrical and

accurate beam steering characteristics of our optically controlled lens antenna. The latest measurements demonstrate a wide field-of-view and highlight a 3-order-of-magnitude increase in beam rates to those presented previously. Demonstrations will include both 94 and 188 GHz variants in both transmission and reflection piFZPA configurations, highlighting the relative advantages and trade-offs in both architectures.

9078-14, Session 3

A millimeter-wave lithographic imaging spectrometer

Justus A. Brevik, National Institute of Standards and Technology (United States)

We present the results on the development of a novel on-chip millimeter-wave imaging spectrometer. Conventional millimeter-wave imaging spectrometers rely on interference or spatial dispersion of light to measure power in narrow frequency bands across a broad spectrum. In this novel approach, light coupled to a broadband antenna is channelized into several hundred adjacent, narrow bands using high quality factor superconducting microwave resonators. The power in each channel is measured using a sensitive superconducting transition-edge sensor (TES) bolometer. Due to the compact nature of this technique, hundreds of pixels can be packed into a focal plane to create an imaging spectrometer.

9078-15, Session 3

Polarization effects on heterodyne detection and imaging using glow discharge detector at millimeter wavelengths

Avihai Aharon Akram, Ben-Gurion Univ. of the Negev (Israel) and Ariel Univ. (Israel); Daniel Rozban, Assaf Levanon, Ben-Gurion Univ. of the Negev (Israel); Amir Abramovich III, Ariel Univ. (Israel); Natan S. Kopeika, Ben-Gurion Univ. of the Negev (Israel)

A miniature neon indicator lamp, also known as a Glow Discharge Detector (GDD), costing about 50 cents, was found to be an excellent room temperature THz radiation detector. Polarization effects on heterodyne detection were investigated in this work. In heterodyne detection, because of the dot product relationship between signal electric field (ES) and local oscillator (LO) electric field (Elo), optimal operation of heterodyne detection is obtained when ES and Elo are of the same polarization. Preliminary results at 300 GHz showed better sensitivity by a factor of 20 with only 56 microwatt local oscillator power using heterodyne compared to direct detection. Further improvement of the detection sensitivity can be achieved if the LO power (Plo) is increased. In this work investigation of polarization effects in heterodyne detection using neon indicator lamp GDD was carried-out. Experimental results of heterodyne detection at 300 GHz showed that an intermediate frequency (IF) signal was obtained for orthogonal polarization of the LO and signal, in contradiction to the theory. Also, our latest imaging results using Glow Discharge Detector at millimeter wavelengths will be shown in this work.

9078-16, Session 3

Sensor for the microwave imaging system based on Josephson Junction

Lijia Chen, Jiaran Qi, Nannan Wan, Jinghui Qiu, Alexander Denisov, Harbin Institute of Technology (China)

There exists big interest to develop the principal technology for the construction focal plane matrix for the passive Millimeter Wave Imaging systems. Integration of plurality of the receivers or the radiometers as an individual pixel into a matrix receiving systems seems efficient for the realization of “radio-vision” or imaging systems without scanning if small-sized sensors with good operating parameters are available. Without doubt various current technical realization which have place in this field of knowledge depend on the concrete principal trends of the scientific world level teams which move forward their principal achievements.

9078-17, Session 3

Design and operation of ACTPol: a millimeter wavelength polarization sensitive receiver for the Atacama Cosmology Telescope

Benjamin L. Schmitt, Univ. of Pennsylvania (United States) and for the ACTPol Collaboration (United States)

B. L. Schmitt, for the ACTPol Collaboration

We highlight considerations for the design and operation of ACTPol, a new receiver for the Atacama Cosmology Telescope (ACT), capable of making polarization-sensitive, millimeter-wavelength observations of the Cosmic Microwave Background (CMB) at arcminute angular scales. ACT is a six-meter telescope located in northern Chile, dedicated to enhancing our understanding of the structure and evolution of the early Universe by direct measurement of the CMB. We describe the design of the ACTPol focal plane at full-deployment, consisting of dual 150 GHz array package modules and a multichroic array package with simultaneous 90 GHz and 150 GHz sensitivity. Each of these detector array packages reside behind a set of custom-designed, high-purity silicon reimaging optics with a novel anti-reflective coating geometry, the characteristics of which will be detailed. Each array package module consists of ~1000 transition-edge sensor (TES) bolometers used to measure the response of ~500 feedhorn-coupled polarimeters, enabling characterization of the linear orthogonal polarization of incident CMB radiation. The polarimeters are arranged in three hexagonal and three semi-hexagonal silicon wafer stacks, mechanically coupled to an octakaidecagonal, monolithic corrugated silicon feedhorn array (~140 mm diameter). Readout of the TES polarimeters is achieved using time-division SQUID multiplexing. Each array package is cooled using a custom-designed dilution refrigerator providing a 100 mK bath temperature to the detectors, which have a target Tc of 150 mK. Given the unique cryomechanical constraints associated with this large-scale monolithic superconducting focal plane, we address the design considerations necessary for integration with the optical and cryogenic elements of the ACTPol receiver. With first light achieved in July 2013, details of the ACTPol receiver deployment and early results will be highlighted. Finally, specific consideration will be given to the context of these associated technologies and their synergistic application supporting allied field applications, including interests in national security, counterterrorism, and nuclear nonproliferation. The NIST 350 GHz Imager will be highlighted as an example of a standoff imaging system that has successfully leveraged integrated technologies originally developed for millimeter-wavelength cosmology applications, within systems such as ACTPol, for use in the security and defense sectors.

9078-18, Session 4

Reconstruction techniques for sparse multistatic linear array microwave imaging

David M. Sheen, Thomas E. Hall, Pacific Northwest National Lab. (United States)

Sequentially-switched linear arrays are an enabling technology for a number of near-field microwave imaging applications. Electronically sequencing along the array axis followed by mechanical scanning along an orthogonal axis allows dense sampling of a two-dimensional aperture in near real-time. The Pacific Northwest National Laboratory (PNNL) has developed this technology for several applications including concealed weapon detection, ground-penetrating radar, and non-destructive inspection and evaluation. These techniques form three-dimensional images by scanning a diverging beam swept frequency transceiver over a two-dimensional aperture and

mathematically focusing or reconstructing the data into three-dimensional images. Recently, a sparse multi-static array technology has been developed that reduces the number of antennas required to densely sample the linear array axis of the spatial aperture. This allows a significant reduction in cost and complexity of the linear-array-based imaging system. The sparse array has been specifically designed to be compatible with Fourier-Transform-based image reconstruction techniques; however, there are limitations to the use of these techniques, especially for extreme near-field operation. In the extreme near-field of the array, back-projection techniques have been developed that account for the exact location of each transmitter and receiver in the linear array and the 3-D image location. In this paper, the sparse array technique will be described along with associated Fourier-Transform-based and back-projection-based image reconstruction algorithms. Simulated and measured imaging results are presented that show the effectiveness of the sparse array technique along with the merits and weaknesses of each image reconstruction approach.

9078-19, Session 4

Investigation of radio astronomy image processing techniques for use in the passive millimetre-wave security screening environment

Christopher T. Taylor, The Univ. of Manchester (United Kingdom); Simon J. Hutchinson, Neil A. Salmon, Manchester Metropolitan Univ. (United Kingdom); Peter N. Wilkinson, The Univ. of Manchester (United Kingdom); Colin D. Cameron, QinetiQ Ltd. (United Kingdom)

Image processing techniques can be used to improve the cost-effectiveness of future interferometric Passive MilliMetre Wave (PMMW) imagers. The implementation of such techniques will allow for a reduction in the number of collecting elements whilst ensuring adequate image fidelity is maintained. Various techniques have been developed by the radio astronomy community to enhance the imaging capability of sparse interferometric arrays. The most prominent are Multi-Frequency Synthesis (MFS) and non-linear deconvolution algorithms, such as the Maximum Entropy Method (MEM) and variations of the CLEAN algorithm. This investigation focuses on the implementation of these methods in the de-facto standard for radio astronomy image processing, the Common Astronomy Software Applications (CASA) package, building upon the discussion presented in Taylor et. al, SPIE 8362. Starting from the development of software to convert target image data into a format suitable for CASA we describe a series of simulations that exploit the highlighted deconvolution and MFS algorithms. The primary target application used for our investigation is an outdoor security scanner for soft-sided Heavy Goods Vehicles. A quantitative analysis of the effectiveness of the aforementioned image processing techniques is presented, with thoughts on the potential cost-savings such an approach could yield. Consideration is also given to how the implementation of these techniques in CASA might be adapted to operate in a near-field environment. This may enable a much wider usability by the imaging community outside of radio astronomy and thus would be directly relevant to portal screening security systems in the microwave and millimetre wave bands.

9078-21, Session 4

DFT calculated THz absorption spectra of water clusters

Lulu Huang, Samuel G. Lambrakos, U.S. Naval Research Lab. (United States); Andrew Shabaev, George Mason Univ. (United States); Noam Bernstein, U.S. Naval Research Lab. (United States); Lou Massa, Hunter College (United States)

Calculations are presented of vibrational resonance structure at THz frequencies for a 38 molecule cluster of H2O using density functional theory (DFT). This resonance structure is due to coupling of molecular vibrational modes. In particular, the coupling among resonance modes provides a reasonable molecular level interpretation of spectral features associated with THz excitation of molecular clusters. THz excitation is associated with frequencies that are characteristically perturbative to molecular electronic states, in contrast to frequencies that can induce appreciable electronic state transition. Owing to this characteristic of THz excitation, one is able to make a direct association between local oscillations about ground-state minima of molecules comprising a cluster and THz excitation spectra.
The DFT software GAUSSIAN was used for the calculations of vibrational resonance structure presented here.

9078-22, Session 4

Temperature resolution enhancing of commercially available THz passive cameras due to computer processing of images

Vyacheslav A. Trofimov, Vladislav V. Trofimov, Igor E. Kuchik, Lomonosov Moscow State Univ. (Russian Federation)

Using the original approaches for computer processing of images captured by THz passive cameras, manufactured by various companies, we demonstrate new opportunities for the detection of concealed objects. Computer processing of images results in a temperature resolution enhancing of cameras. Therefore, in particular, we demonstrate new possibilities for seeing the clothes details, which raw images, produced by the THz cameras, do not allow to see. We achieve good quality of the image due to applying various spatial filters to show independence of processed images on math operations. This result demonstrates a validity of observable objects.
We consider images produced by THz passive cameras manufactured by Microsemi Corp. and ThruVision Corp

9078-25, Session Posters-Thursday

Passive millimeter-wave image analysis for concealed object detection and classification

Seokwon Yeom, Dong-Su Lee, Daegu Univ. (Korea, Republic of)

Millimeter wave (MMW) imaging has wide applications in security and surveillance. Although a passive MMW imaging system can scan people in both indoors and outdoors as a stand-off type sensor, the image quality is often degraded by the diffraction limit and the low signal level. This paper addresses concealed-object detection and classification based on geometric features. Concealed object region is extracted by the multi-level segmentation. Principal component analysis regularizes the extracted region in terms of translation and rotation. A geometric-based feature vector is composed of shape descriptors, which can achieve scale and orientation-invariant and distortion-tolerant property. Euclidean distance is measured between the normalized feature vectors of input and reference objects. Experiments is performed for five man-made objects such as gun, axe, knife, water pack, and lotion bottle showing the reliable classification results of the concealed object.

9078-23, Session 6

Plasmonic terahertz optoelectronics for higher performance terahertz imaging systems *(Invited Paper)*

Christopher W. Berry, Ning Wang, Mohammad R. Hashemi, Mona Jarrahi, Univ. of Michigan (United States)

We introduce new designs of high performance terahertz imaging systems based on plasmonic terahertz optoelectronics. We have recently demonstrated that the use of plasmonic contact electrodes in a

photoconductive terahertz source and detector manipulates the spatial distribution of photocarriers in the device active area and enhances the number of photocarriers in nanoscale distances from contact electrodes significantly, enabling efficient collection of the majority of carriers in a sub-picosecond time scale. It also allows increasing photoconductor active area without a considerable impact on device parasitics, boosting the maximum terahertz radiation power and detection sensitivity by preventing the carrier screening effect and thermal breakdown at high optical pump powers.
We have experimentally demonstrated two orders of magnitude higher terahertz powers and more than one order of magnitude higher terahertz detection sensitivities from our first generation plasmonic photoconductive sources and detectors in comparison with similar photoconductive terahertz sources and detectors with non-plasmonic contact electrodes. As a result, use of plasmonic photoconductive terahertz sources and detectors in a terahertz imaging setup offers more than three orders of magnitude higher signal-to-noise ratio levels compared to existing terahertz imaging systems. This could offer numerous opportunities for e.g., medical diagnostics, biological sensing, pharmaceutical quality control, and security screening.

9078-24, Session 6

Resonant-tunneling-enhanced plasmonic terahertz devices *(Invited Paper)*

Berardi Sensale Rodriguez, Univ. of Utah (United States); Huili G. Xing, Univ. of Notre Dame (United States)

This talk discusses active terahertz devices based on the interplay between resonant tunneling and electron plasma waves in semiconductor hetero-structures. At high frequency, two dimensional electron gases in HEMT-like structures can allow for collective motion of electrons, the so-called electron-plasma waves, whose group velocity might be more than one order of magnitude larger than the electron-drift velocity therefore enabling transit times associated with terahertz frequencies. Devices relying in electron plasma waves have been recently demonstrated to be capable of achieving very sensitive THz detection at room temperatures. As recently proposed, addition of an element enabling resonant tunneling, such as a double potential barrier as the gate-stack in a HEMT, can further improve the THz performance of these devices. Distributed negative differential conductance in this case provides a gain medium for the plasma waves excited in the semiconductor 2DEG; i.e. the device behaves as an "active transmission-line". Based on this phenomena, device configurations enabling very sensitive THz detection or power gain at THz frequencies will be discussed in several material systems.

9079-1, Session 1

The Warfighter Associate: decision-support software agent for the management of intelligence, surveillance, and reconnaissance (ISR) assets

Norbou Buchler, Laura R. Marusich, U.S. Army Research Lab. (United States); Stacey Sokoloff, VELOXITI (United States)

A unique and promising intelligent agent plug-in technology for Mission Command Systems— the Warfighter Associate (WA)— is described that enables individuals and teams to respond more effectively to the cognitive challenges of Mission Command, such as managing limited intelligence, surveillance, and reconnaissance (ISR) assets and information sharing in a networked environment. The WA uses a doctrinally-based knowledge representation to model role-specific workflows and continuously monitors the state of the operational environment to enable decision-support, delivering the right information to the right person at the right time. Capabilities include: (1) analyzing combat events reported in chat rooms and other sources for relevance based on role, order-of-battle, time, and geographic location, (2) combining seemingly disparate pieces of data into meaningful information, (3) driving displays to provide users with map based and textual descriptions of the current tactical situation, and (4) recommending courses of action with respect to necessary staff collaborations, execution of battle-drills, re-tasking of ISR assets, and required reporting. The results of a scenario-based human-in-the-loop experiment are reported. The underlying WA knowledge-graph representation serves as state traces, measuring aspects of Soldier decision-making performance (e.g. improved efficiency in allocating limited ISR assets) across runtime as dynamic events unfold on a simulated battlefield.

9079-2, Session 1

Summary of level 5 metrics for multi-intelligence fusion

Erik P. Blasch, Air Force Research Lab. (United States)

Over the last decade, there has been interest in presenting information fusion solutions to the user and ways to incorporate visualization, interaction, and command and control. However, there is still a need to investigate which and what metrics (e.g., measures of performance and measures of effectiveness) are important to users (i.e., operators, analysts, and engineers). Using the measures of merit (or figures of merit), we seek to organize and discuss various metrics for user understanding of machine fusion solutions for situation awareness. As an example, we present a systems solution example for multi-intelligence information fusion that demonstrates the many issues surrounding the useful of metrics in Level 5 fusion such as interoperability standards, integration of man and machines, and efficient networking for distribution user situation understanding.

9079-3, Session 1

Application of distributed virtual cluster management to emulated tactical network experimentation

Kelvin M. Marcus, U.S. Army Research Lab. (United States)

The U.S Army Research Laboratory (ARL) has built a "Network Science Research Lab" to support research that aims to improve their ability to analyze, predict, design, and govern complex systems that interweave the social/cognitive, information, and communication network genres. Researchers at ARL and the Network Science Collaborative Technology Alliance (NS CTA), a collaborative research alliance funded by the ARL, conducted experimentation to determine if automated network monitoring tools and task-aware agents deployed within an emulated tactical wireless network could potentially increase the retrieval of relevant data from heterogeneous distributed information nodes. ARL and NS-CTA required the capability to perform this experimentation over clusters of heterogeneous nodes with emulated wireless tactical networks where each node could contain different operating systems, application sets, and physical hardware attributes. Researchers utilized the Dynamically Allocated Virtual Clustering management system (DAVC) to address each of the infrastructure support requirements necessary in conducting their experiment. The DAVC is an experimentation infrastructure that provides the means to dynamically create, deploy, and manage virtual clusters of heterogeneous nodes within a cloud computing environment based upon resource utilization such as CPU load, available RAM and hard disk space. The DAVC uses 802.1Q Virtual LANs (VLANs) to prevent experimentation crosstalk and to allow for complex private networks. Clusters created by the DAVC system can be utilized for software development, experimentation, and integration with existing hardware and software. The goal of this paper is to explore how ARL and the NS-CTA leveraged the DAVC to create, deploy and manage multiple experimentation clusters to support their experimentation goals.

9079-4, Session 1

Agile sensor tasking for COIST using natural language knowledge representation and reasoning

David Braines, IBM United Kingdom Ltd. (United Kingdom); Geeth de Mel, IBM Thomas J. Watson Research Ctr. (United States); Christopher Gwilliams, Christos Parizas, Diego Pizzocaro, Alun D. Preece, Cardiff Univ. (United Kingdom)

We describe a system architecture aimed at supporting Intelligence, Surveillance, and Reconnaissance (ISR) activities in a Company Intelligence Support Team (COIST) using natural language-based knowledge representation and reasoning, and semantic matching of mission tasks to ISR assets. We illustrate an application of the architecture using a High Value Target (HVT) surveillance scenario which demonstrates semi-automated matching and assignment of appropriate ISR assets based on information coming in from existing sensors and human patrols operating in an area of interest and encountering a potential HVT vehicle. We highlight a number of key components of the system including (i) Soldiers on the field providing input in natural language via spoken voice to a mobile device, which is then processed to machine-processable Controlled Natural Language (CNL) and confirmed with the Soldier; (ii) COIST analysts obtaining real-time situation awareness on the unfolding events through fused CNL information – with associated explanatory rationale – via tools available at the Command and Control (C2); and (iii) being supported by the system in tasking available assets (subject to management and security policies, also expressed in CNL) to localize and track the HVT. The system demonstrates various modes of operation including: automatic task assignment following inference of new high-importance information, as well as semi-automatic processing, providing the COIST analyst with options and associated rationale in order for them to make a reasoned asset-allocation decision in the context of their mission.

9079-5, Session 1

Evaluation and prioritization of scientific data based on its level of support or refutation of an experimental thesis

Jeremy Straub, The Univ. of North Dakota (United States)

Missions over contested territory, space missions (particularly those operating beyond Earth-orbit) and many other mission types are generally are constrained by their communications capabilities. These spacecraft have the capability of collecting far more data than they can ever send back to Earth. For this reason, data must be selected to maximize performance relative to science and other objectives. Many missions achieve this by sending back low-quality representations of data to allow controllers to determine what data should be prioritized for transmission and in what order. For example, 'thumbnail' images are sent back to allow controllers to determine what images they may wish to download in full resolution. This low granularity data is not a panacea, however, as it can overlook effects that may make the higher quality data unusable (e.g., image blurring may not be noticeable in a low-resolution version of an image). It may also miss important (perhaps, unanticipated) phenomena present in the high-resolution data but smoothed over in the lower-resolution data. The transmission of this low-resolution data for selection purposes also consumes transmission capability that could be used to transfer additional high-resolution files.

For this reason, onboard analysis of data to determine whether it should be transmitted back to Earth and, if so, at what level of priority is thus highly desirable. This paper presents an algorithm for analyzing image data with regards to several hypotheses about the presence of various objects. This example demonstrates how data can be prioritized based on its relevance in supporting or refuting a scientific thesis. Extrapolation from the image data to other data types is also discussed.

9079-6, Session 1

Secure complex event processing in a heterogeneous and dynamic network

Thilina M. Buddhika, Indrakshi Ray, Colorado State Univ. (United States); Mark H. Linderman, Air Force Research Lab. (United States); Anura Jayasumana, Colorado State Univ. (United States)

Battlefield monitoring involves collecting streaming data from different sources, transmitting the data over a heterogeneous network, and processing queries in real-time in order to respond to events in a timely manner.

Nodes in these networks differ with respect to their trustworthiness, processing, storage, and communication capabilities. Links in the network differ with respect to their communication bandwidth. The topology of the network itself is subject to change, as the nodes and links may become unavailable. Continuous queries executed in such environments must also meet some quality of service (QoS) requirements, such as, response time and throughput. Data streams generated from the various nodes in the network belong to different security levels; consequently, these must be processed in a secure manner without causing unauthorized leakage or modification. We demonstrate how to process queries and events in a secure manner in such a dynamic and heterogeneous environment.

9079-7, Session 1

Practical use of a framework for network science experimentation

Andrew Toth, U.S. Army Research Lab. (United States); Flavio Bergamaschi, IBM United Kingdom Ltd. (United Kingdom)

No Abstract Available

9079-8, Session 2

Multisensor data fusion for the northern border low-flying aircraft detection and surveillance

David L. Masters, U.S. Dept. of Homeland Security (United States); Weiqun Shi, The MITRE Corp. (United States)

Criminal and drug trafficking organizations use small aircraft such as small private planes, helicopters, and ultra-light aircraft to deliver illicit cargo and contraband across remote sections of the Northern US border. These organizations utilize aircraft with small signatures and operate at low altitudes across remote and rugged sections of the border to take advantage of terrain masking to avoid detection. To address the challenges and the asymmetric threat they present, the Department of Homeland Security (DHS) Science and Technology Directorate (S&T) is presently leading the development of a multi-sensor prototype system for field use for the detection, tracking and classification of low flying / low observable aircraft along the difficult terrain of the northwest border. The system is an integrated suite of field sensors including a bistatic radar, acoustic arrays, visual and thermal imagers, communications, remote power, computational processing, data storage, air picture data manipulation and visualization. This paper describes the sensor fusion process and the enhancement. The fusion tracker combines measurements from a bistatic radar system and an acoustic sensor system into a uniform air surveillance picture of the coverage region. Measurements from both systems consist of latitude, longitude, and sometimes altitude along with estimates of error covariance. Tracks are filtered using a Kalman filter, and the measurements are associated with existing tracks using a Munkres nearest-neighbor algorithm. The output of the tracker cues optical and infrared cameras to point and zoom on a potential target of interest. Additionally, tracker output is transmitted to a remote database for later review. Results from the recent Long Duration Field Test will be presented.

9079-9, Session 2

Architecture for persistent surveillance using mast and UAS-based autonomous sensing with bio-inspired technologies

Jerry A. Burman, Intelligent Recognition Systems (United States)

Sensor networks are required to provide timely and accurate information about events on the ground to dismounts and upper echelons in support of DoD operations. Current unattended ground sensor (UGS) networks are comprised of sparse heterogeneous sensors that provide temporal detection of events. Persistent surveillance may also include the use of ground based mast sensor systems for detecting and tracking personnel and vehicles. The classification of disparate sensor data can be realized by fusing data from multiple sensors. Examples of disparate data include time of arrival, time difference of arrival, angle of arrival data and imagery. The DoD is seeking to enhance the performance of sensor networks through persistent surveillance that leverages aerial and terrestrial platforms to disseminate relevant information. A key Army requirement is to rapidly exfiltrate data to enhance event detection/time of occurrence, source localization, event classification, direction of movement of adversarial activities and the verification of spatial events from sparsely distributed disparate sensors that comprise heterogeneous sensor networks.

A sophisticated real time architecture and network for capturing relevant battlefield information of personnel and terrestrial events from a network of mast based imaging and unmanned aerial systems (UAS) with target detection, tracking, classification and visualization in support of command post operations is presented. Applications like persistent surveillance of wide area borders of personnel and vehicles is achieved using a unique spatially and temporally invariant motion detection and tracking algorithm for mast based cameras in combination with aerial remote sensing to autonomously monitor heterogeneous unattended ground based sensor networks. UAS autonomous routing is achieved using bio-inspired algorithms that mimic how bacteria locate nutrients in their environment. Results include field test data, performance and lessons learned.

9079-10, Session 2

Real-time movement detection and analysis for video surveillance applications

Nicolas Hueber, Christophe Hennequin, Pierre Raymond, Jean-Pierre Moeglin, Institut Franco-Allemand de Recherches de Saint-Louis (France)

Pedestrian's flow along critical infrastructures like pipes, train or vehicle tracks, etc. as well as his behaviour in urban environment is of major interest in surveillance activities. The goal is to anticipate illicit, suspicious and dangerous actions. For this, we developed an all-in-one small autonomous system which delivers high level statistics and, in some specific cases, alerts.

This situational awareness project led us to manage efficiently the scene and to perform movement analysis. Many dynamic background extraction algorithms have been compared to reach the degree of robustness against natural and urban environment perturbations and also to match the embedded implementation constraints.

When one movement is detected in the scene, split in contiguous elementary regions, a specific pedestrian pattern is applied to detect and determine its direction. Numerous high level information is also locally extracted which does not require a high bandwidth media to be transmitted. A set of more than ten prototypes, still in place, has been deployed over wide city centre for reaching macroscopic level of analysis. The results demonstrate the relevance of the delivered information and how they can be usefully fused to help the supervisor making a decision.

Among them, the flow density map highlights pedestrian trajectory deviations along streets.

Furthermore, a tracking algorithm has been realised to be coupled with this first system in order to extend its capacity to surveillance applications in natural scene. The overall proposed algorithm steps have been described and discussed in terms of efficiency and computational costs.

9079-11, Session 2

Robust human detection, tracking, and recognition in crowded urban areas

Hai-Wen Chen, Mike McGurr, Booz Allen Hamilton Inc. (United States)

Security surveillance cameras play an important role in protecting our daily life as well as in helping the law enforcement to hunt down the criminals and terrorists when crimes and terror attacks occurred – the recent Boston Marathon Terror Attack case is such an example. However, excessive video data from a crowded urban area post a huge load for the human analysts to timely trace down the persons accountable. An automated human detection, tracking, and recognition system is urgently needed.

In this paper, we present algorithms we recently developed to support an automated security surveillance system for very crowded urban areas. There are several technical challenges for human (vs. vehicles) detection and tracking: 1) The non-rigid shape and form of human bodies make it difficult to apply matched filter techniques, and 2) Human motion has much more complicated moving kinematic patterns than vehicles. It is more difficult for human tracking to predict the forward (future) positions as well as the tracking gate size. In our approach for human detection, the color features are obtained by taking difference of R, G, B spectrum and by converting R, G, B to HSV (Hue, Saturation, Value) space. Morphological patch filtering and regional minimum and maximum segmentation on the extracted features are applied for target detection. The human tracking process approach include 1) color and intensity feature matching tracking candidate selection, 2) adaptive track gate size selection for reducing false tracking probability, and 3) forward position prediction based on previous moving speed and direction for continuing tracking even when detections are missed from frame to frame. The Human target recognition is improved with a Super-Resolution Image Enhancement (SRIE) process. The process can improve target resolution by 3-5 times and can simultaneously process many targets that are tracked. Our approach can project tracks from one camera to another camera with a different perspective viewing angle to obtain additional biometric features from different perspective angles, and to continue tracking the same person from the 2nd camera even though the person moved out of the FOV of the 1st camera - 'Tracking Relay'. Preliminary tests of our algorithms indicate than high probability of detection can be achieved for both moving and stationary human. Our algorithms can simultaneously track up to 100 human targets with averaged tracking period (time length) longer than the performance of the current state-of-the-art.

9079-12, Session 2

Advanced MicroObserver(R) UGS integration with and cueing of the BattleHawk(TM) squad level loitering munition and UAV

Robert L. Steadman, John Finklea, Dean Frost, Sean Deller, James Kershaw, Textron Systems Corp. (United States)

Textron's Advanced MicroObserver® is a next generation remote unattended ground sensor system (UGS) for border security, infrastructure protection, and small combat unit security. The original MicroObsever® is a sophisticated seismic sensor system with multi-node fusion that supports target tracking. This system has been deployed in combat theaters. The system's seismic sensor nodes are uniquely able to be completely buried (including antennas) for optimal covertness. The advanced version adds a wireless day/night IR camera, cued by seismic tracking, with sophisticated target discrimination and automatic frame capture features. Also new is a field deployable Gateway configurable with a variety of radio systems and flexible networking, an important upgrade that enabled this research. BattleHawk™ is a small tube launched Unmanned Air Vehicle (UAV) with a munition designed to transmit video so that an operator can search for and acquire a target day or night, select a target for attack, and execute terminal dive to destroy the target. It is designed as a lightweight squad level asset carried by an individual infantryman.

Although BattleHawk has the best loiter time in its class, it's still relatively short compared to large UAVs, also it's a one-shot asset in its munition configuration. Therefore Textron conducted research to determine if there was military utility in having the highly persistent MicroObserver system cue BattleHawk's launch and vector it to beyond visual range targets for engagement. This paper describes that research; the system configuration implemented, and the results of field testing that was performed on a government range early in 2013. On the integrated system that was implemented, MicroObserver seismic detections activated that system's camera which then automatically captured images of the target. The geo-referenced and time-tagged MicroObserver target reports and images were then automatically forwarded to the BattleHawk Android-based controller. This allowed the operator to see the intruder (classified and geo-located) on the map based display, assess the intruder as likely hostile (via the image), and launch BattleHawk with the pre-loaded target coordinates. The operator was thus able to quickly acquire the intended target (without a search) and initiate target engagement immediately. System latencies were a major concern addressed during the research.

9079-13, Session 3

Anomaly determination system architecure

Michael A. Kolodny, U.S. Army Research Lab. (United States)

No Abstract Available

9079-14, Session 3

An algorithm for monitoring the traffic on a less-travelled road using multi-modal sensor suite

Thyagaraju Damarla, Hao Vu, Gary Chatters, U.S. Army Research Lab. (United States); James M. Sabatier, Univ. of Mississippi (United States)

As a part of an anomaly detection project, an unattended ground sensor (UGS) system, consisting of multi-model suite of acoustic, seismic, passive infrared (PIR), and ultrasonic sensors, is deployed alongside a road with intermittent traffic. The goal of the project is to observe the traffic patterns of the vehicles and people, and determine if there are any outliers in the patterns. As a part of the anomaly detection project, one goal is to correlate outliers (anomalies) in information obtained on social media. The general travel patterns on the road include vehicles travelling during the morning and evening hours going to work and people walking during their lunch break. The sensors suite selected mainly consists of sensors that require low power for operation and last a long time.

The output of each sensor is analyzed to classify the targets as ground vehicles, humans and airborne vehicles. The algorithm is also used to count the number of targets belonging to each type and store the information for anomaly detection. In this paper, we describe the classifier algorithms used for acoustic, seismic, and PIR sensor data. The acoustic data are analyzed for specific features pertaining to vehicles and human voices. Cepstral coefficients of seismic signatures are used to classify the targets. The seismic data are also analyzed for cadence of a person walking and the PIR data are used to estimate approximate size of a target to determine the type of target. We provide the results on each classifier as well as the confusion matrices. We also describe the UGS data collection system used.

9079-15, Session 3

Actively learning to distinguish suspicious from innocuous anomalies in a batch of vehicle tracks

Zhicong Qiu, David J. Miller, The Pennsylvania State Univ. (United States); Brian Stieber, Tim Fair, Toyon Research Corp. (United States)

We investigate the problem of actively learning to distinguish "suspicious/interesting" anomalous vehicle tracks from "innocuous/uninteresting" ones, starting from scratch, i.e. with no initially known suspicious examples nor any prior knowledge of what an operator would deem to be "suspicious". This two-class problem is challenging both because it is unknown a priori which features may characterize the suspicious (unknown unknown) class and because of huge labeled set class imbalance, even after some suspicious examples have been identified. We present a comprehensive solution, by which a classifier learns to discriminate suspicious from innocuous, and in so doing learns the subset of features on which to accurately base such decisions. Our solution encompasses: i) judicious choice of (p-value based) features that condition on the road segment/spatial cell, as well as features that capture particular maneuvers (e.g. U-turns); ii) semi-supervised learning, which exploits information in the unlabeled (test batch) tracks, and iii) evaluation of several classifier models (SVMs, logistic regression). We find that two active labeling streams are necessary in practice, in order to have most efficient classifier learning while also forwarding the most actionable tracks. Experiments on wide-area motion video tracks, extracted via a system developed in-house at Toyon Corporation, demonstrate the strong ROC AUC performance achievable by our system with sparing use of operator-based active labeling.

9079-16, Session 4

Interoperability and coalition operations: coalition C2 and its implications for ISR *(Invited Paper)*

Matthew J. Martin, U.S. Air Force (United States)

No Abstract Available

9079-17, Session 4

U.S. Unified Vision 2014 contributions *(Invited Paper)*

Lebert Powell, Secretary of the Air Force/Acquisition (United States)

Discussion on Unified Vision 2014

9079-18, Session 4

Interoperability as a design construct during the development of quick-reaction capability systems

Kevin L. Priddy, Air Force Research Lab. (United States)

No Abstract Available

9079-19, Session 4

ITA Scenario 2.0: technology impact in future coalition operations

Paul Sullivan, Intelpoint Inc. (United States); Geeth de Mel, IBM Thomas J. Watson Research Ctr. (United States); Tien Pham, U.S. Army Research Lab. (United States); Seraphin Calo, IBM Thomas J. Watson Research Ctr. (United States); David Braines, IBM United Kingdom Ltd. (United States); Thomas La Porta, The Pennsylvania State Univ. (United States); Alun D. Preece, Cardiff Univ. (United Kingdom); Alice Toniolo, Univ. of Aberdeen (United Kingdom); Ting He, IBM Thomas J. Watson Research Ctr. (United States); Timothy J. Norman, Univ. of Aberdeen (United Kingdom)

Commanders never have the luxury of having to deal with only one crisis at a time due to the dynamism in the environments they operate in; to function effectively in such settings, they need to employ various Intelligence Surveillance Reconnaissance (ISR) assets, be they traditional or non-traditional such as "Human as a Sensor". These assets provide commanders with better situational awareness, thus allowing them to make informed decisions in time critical situations. Motivated by this, in this document we will provide an overarching scenario for the International Technology Alliance (ITA) program so that the technologies developed in the program can come together cohesively to solve a set of identified challenges. The scenario is based on a collection of vignettes that highlight an evolving situation in a notional country- Sincor- after a campaign to liberate it from a dictatorial regime. The Combined Joint Task Force (CJTF) commander is entrusted with maintaining the fragile peace and to ensure the stability. In order to achieve this goal the commander must be able to understand all facets of his Area of Responsibility (AOR) and remain aware of all on-going activities that may affect his mission. The coalition itself adds another layer of complexity to his challenge as different members have varying degrees of capabilities and different reporting procedures which need to be discovered and combined to make informed decisions. Through this scenario we

identify a set of challenges and discuss how the technology developed in the ITA can assist in a complex military environment.

9079-21, Session 4

Power-managed Terra Harvest controller for long life missions

Matthew J. Rohrer, Richard D. Porter, Robert Fish, McQ, Inc. (United States)

The Defense Intelligence Agency's Terra Harvest program, launched in 2009, is developing an open, integrated battlefield unattended ground sensors (UGS) architecture that ensures interoperability among disparate UGS components and systems. The Terra Harvest controller provides management, monitoring, and control functions; acquires data from sensor assets; and disseminates data to other controllers or to domain-specific software components. Assets are system components that can be tasked or reconfigured to produce a payload (data, information, knowledge, command) for processing and dissemination. Data is disseminated via industry-standard communication services or vendor-provided, domain-specific communication service that is registered within the Terra Harvest framework, e.g., Broadband Global Area Network (BGAN), Common Sensor Radio, Iridium, or Security Equipment Integration Working Group (SEIWG) radio. [1]

McQ Inc. is developing a second generation Terra Harvest controller with power management features and USB connected assets. These capabilities will improve the operational utility and extend mission durations of the Terra Harvest Controller.

9079-22, Session 5

Distributed fusion and automated sensor tasking in ISR systems

Jurgo Preden, Raido Pahtma, Sergei Astapov, Andri Riid, Leo Motus, Johannes Ehala, Erki Suurjaak, Tallinn Univ. of Technology (Estonia)

Modern Intelligence, Surveillance and Reconnaissance (ISR) systems are increasingly being assembled from autonomous systems, so the resulting ISR system is a System of Systems (SoS). In order to take full advantage of the capabilities of the ISR SoS, the architecture and the design of these SoS should be different from the approaches currently used in design of ISR systems.

The tasks performed by ISR SoS can well go beyond basic data acquisition, conditioning and communication. One of the tasks that can be performed by the ISR SoS is data fusion, classification and tracking (and conditional sensor tasking for additional data acquisition), which is an extremely challenging task in this context, especially if the fusion is performed in a distributed manner.

Our premise for the ISR SoS design and deployment is that the system is not designed as a complete system, where the capabilities of individual data providers are considered and the interaction paths, including communication channel capabilities, are specified at design time. Instead, we assume a loosely coupled SoS, where the data needs for a specific fusion task are described at a high level and data providers (i.e., sensor systems) required for a specific fusion task are discovered dynamically, the selection criteria for the data providers being the type and properties of data that can be provided by the specific data provider.

The data exchange in the SoS follows a subscription based model, where information with specific properties is requested from the ISR system and the individual systems start performing data acquisition and fusion tasks once a request has been received. Based on the requests received from information consumers the sensor nodes are able to task other sensor nodes (mobile or static) to provide data needed for providing complete situational information to the information consumer.

There are many challenges involved in the design, development and deployment for such a SoS as the data providers are not synchronized and the data exchange paths can not be known at design or deployment time. As the individual sensor nodes are not synchronized temporally (as there is no central authority to provide synchronization) the temporal coherence of data becomes an issue.

In addition to temporal issues also the locations of the individual nodes are not known at design time, for which reason the spatial properties of data must be determined, specified and validated to make use of the data in computation.

The sensor systems perform classification and tracking both locally but also in a distributed manner, including both locally acquired information as well as combining data from several sensor nodes. The theoretical concept of mediated interactions is employed to ensure correct exchange of data between individual systems is crucial.

We have showed that it is realistic to employ these principles in a ISR SoS setting in simulations in our previous work [1]. The work described in the current paper applies these principles on a SoS consisting of physical systems. The sensor systems employed are microphone arrays, magnetometers, seismic sensor and also a UAV.

One novelty of the approach is that the individual sensor systems can task other systems, in case information is inferred from the incoming data and it is determined that additional data could be needed to complement the situational information.

In the current paper we present intermediary results from the European Defence Agency project IN-4-STARS, where the SoS ISR design principles described above are applied to an experimental ISR system design and development.

The sensor nodes in question are both mobile and static nodes, having various sensor modalities. the sensors used in the project are microphones, microphone arrays, seismic sensors and UAV with an optical sensor.

[1] Preden, J; Llinas, J.; Rogova, G.; Pahtma, R.; Motus, L. (2013). On-line data validation in distributed data fusion. In: Ground/Air Multisensor Interoperability, Integration, and Networking for Persistent ISR IV: (edit) T. Pham; M. A. Kolodny; K. L. Priddy. SPIE, 2013.

9079-23, Session 5

Exploiting vibration-based signatures for aided target recognition

Scott J. Kangas, Air Force Research Lab. (United States); Lauren Crider, Arizona State Univ. (United States)

Understanding and organizing data is the first step toward exploiting laser vibrometry sensor phenomenology for target classification. A fundamental challenge in robust vehicle classification using vibrometry signature data is the determination of salient signal features and the fusion of appropriate measurements. . A particular technique, Diffusion Maps, has demonstrated the potential to extract intuitively meaningful features [1]. We want to develop an understanding of this technique by validating existing results using vibrometry data. This paper briefly describes the Diffusion Map technique, its application to dimension reduction of vibrometry data, and describes interesting problems to be further explored.

9079-24, Session 5

Stability analyis of laser vibrometry for vechicle classification

Ashley Smith, Wright State Univ. (United States); Scott J. Kangas, Air Force Research Lab. (United States); Arnab Shaw, Wright State Univ. (United States); Matthew P. Dierking, Olga Mendoza-Schrock, Air Force Research Lab. (United States)

Understanding and organizing the stability of data is the first step toward exploiting laser vibrometry sensor phenomenology for target classification.

A fundamental challenge in robust vehicle classification using vibrometry signature data is the determination of salient signal features and the fusion of appropriate measurements. . A particular technique, Diffusion Maps, has demonstrated the potential to extract intuitively meaningful features [1]. We want to develop an understanding of this technique by validating existing results using vibrometry data. This paper briefly describes the Diffusion Map technique, its application to dimension reduction of vibrometry data, and describes interesting problems to be further explored including the stability of signals.

9079-25, Session 5

Long-range dismount activity classification: LODAC

Denis Garagic, Bradley J. Rhodes, Fang Liu, Robert Haslinger, Manuel Cuevas, BAE Systems (United States); Andrew Freeman, Olga Mendoza-Schrock, Air Force Research Lab. (United States)

The Civilian American and European Surface Anthropometry Resource (CAESAR) database containing over 40 anthropometric measurements on over 4000 humans has been extensively explored for pattern recognition and classification purposes using the raw, original data [1-4]. However, some of the anthropometric variables would be impossible to collect in an uncontrolled environment. Here, we explore the use of dimensionality reduction methods in concert with a variety of classification algorithms for gender classification using only those variables that are readily observable in an uncontrolled environment. Several dimensionality reduction techniques are employed to learn the underlining structure of the data. These techniques include linear projections such as the classical Principal Components Analysis (PCA) and non-linear (manifold learning) techniques, such as Diffusion Maps and the Isomap technique. This paper briefly describes all three techniques, and compares three different classifiers, NaÃive Bayes, Adaboost, and Support Vector Machines (SVM), for gender classification in conjunction with each of these three dimensionality reduction approaches

9079-26, Session 5

Gender classification under extended operation conditions

Howard N. Rude, Ryan R. McCoppin, Nathan Koester, Louis A. Tamburino, Mateen M. Rizki, Wright State Univ. (United States); Andrew Freeman, Olga Mendoza-Schrock, Todd V. Rovito, Air Force Research Lab. (United States)

Gender classification is a critical component of a robust image security system. Many techniques exist to perform gender classification using facial features. In contrast, this paper explores gender classification using body features extracted from clothed subjects. Several of the most effective types of features for gender classification identified in literature were implemented and applied to the newly developed Seasonal Weather And Gender (SWAG) dataset. SWAG contains video clips of approximately 2000 samples of human subjects captured over a period of several months. The subjects are wearing casual business attire and outer garments appropriate for the specific weather conditions observed in Midwest. The results from a series of experiments are presented that compare the classification accuracy of systems that incorporate various types and combinations of features applied to multiple looks at subjects at different image resolutions to determine a baseline performance for gender classification.

9079-27, Session 5

Exploiting the SWAG database for gender classification using data mining techniques

Olga Mendoza-Schrock, Air Force Research Lab. (United States); Guozhu Dong, Wright State Univ. (United States)

This paper describes the process used to collect the Seasonal Weather And Gender (SWAG) dataset; an electro-optical dataset of human subjects that can be used to develop advanced gender classification algorithms. Several novel features characterize this ongoing effort (1) the human subjects self-label their gender by performing a specific action during the data collection and (2) the data collection will span months and even years resulting in a dataset containing realistic levels and types of clothing corresponding to the various seasons and weather conditions. It is envisioned that this type of data will support the development and evaluation of more robust gender classification systems that are capable of accurate gender recognition under extended operating conditions.

9079-28, Session 5

Deep learning applied to SWAG

Ryan R. McCoppin, Howard N. Rude, Mateen M. Rizki, Louis A. Tamburino, Wright State Univ. (United States); Olga Mendoza-Schrock, Air Force Research Lab. (United States)

This paper describes the process used to collect the Seasonal Weather And Gender (SWAG) dataset and the application of Deep learning to the data. SWAG is an electro-optical dataset of human subjects that can be used to develop advanced gender classification algorithms. Several novel features characterize this ongoing effort (1) the human subjects self-label their gender by performing a specific action during the data collection and (2) the data collection will span months and even years resulting in a dataset containing realistic levels and types of clothing corresponding to the various operating conditions.

9079-29, Session 5

Laser vibrometry exploitation for vehicle identification

Adam R. Nolan, Andrew J. Lingg, George S. Goley, Etegent Technologies, Ltd. (United States); Scott J. Kangas, Olga Mendoza-Schrock, Andrew Freeman, Air Force Research Lab. (United States)

Vibration signatures sensed from distant vehicles using laser vibrometry systems provide valuable information that may be used to help identify key vehicle features such as engine type, engine speed, and number of cylinders.

While developing algorithms to blindly extract the aforementioned features from a vehicle's vibration signature, it was shown that detection of engine speed and number of cylinders was more successful when utilizing a priori knowledge of the engine type (gas or diesel piston) and optimizing algorithms for each engine type. In practice, implementing different algorithms based on engine type first requires an algorithm to determine whether a vibration signature was produced by a gas piston or diesel piston engine. This paper provides a general overview of the observed differences between datasets from gas and diesel piston engines, and proceeds to detail the current method of differentiating between the two. To date, research has shown that basic signal processing techniques can be used to distinguish between gas and diesel vibration datasets with reasonable accuracy for piston engines of different configurations running at various speeds.

Conference 9080A: Laser Radar Technology and Applications XIX

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9080-1, Session 1

Multi-dimensional laser radars *(Invited Paper)*

Vasyl Molebny, Academy of Technological Sciences of Ukraine (Ukraine); Ove Steinvall, Swedish Defence Research Agency (Sweden)

Despite the term restrictions of “laser detection and ranging”, ladars (laser radars) acquire information not only on range. Any other physical parameter measured by laser radar can have its own dimensionality, which can be that of velocity, temperature, humidity, etc. Some of these parameters are single-dimensional, like temperature. Some can have several dimensions, like temperature distribution in space or temperature dependence on time. Another type of examples yields combinations of several parameters distributed in space and time, like 3D velocity of an object having its 3D position in space, both changing in time. It is similar to human professional activities, where binocular vision is often amplified with instrumental sources of information. For example, car driver has at his disposal a speedometer and a parking radar to get the information on car velocity when driving and on distances to obstacles when parking. Similarly, rendezvous and docking missions, autonomous planetary landing, along with laser ranging, laser altimetry, laser Doppler velocimetry, are thought to have aboard also the 3D ladar imaging. Operating in combinations, they provide more accurate and safer navigation, docking or landing, hazard avoidance capabilities. Critically vital is the information identifying the snipers in a 3D battle-field scene, especially under the urban conditions - detection and identification based on the intensity of the retroreflected illumination in combination with polarization and fluctuation parameters, as well as the data from other sources. Combining thermal imaging with 3D ladar can enrich the information on the functionality of the detected targets: operating engines will give higher thermal contrast. Hyperspectral probing with laser reveals even more parameters of the detected objects, it has sense, for example, for mine detection. Combination with Doppler-based measurements provides more accurate navigation for both space and cruise missile applications. Adding vibrometry creates instrumentation for 3D-based engine diagnostics. Involving velocity and time allows higher dimensionality of information presentation like 4D and even higher. Different algorithms and architectures of lidar-based target acquisition, further reconstruction of 3D images, information fusion and presentation is being discussed with special attention to the technologies of simultaneous single- and multi-beam flash illumination of a scene and including a single-photon focal-plane-array detection.

9080-2, Session 1

Development of three-dimensional wind lidar for space *(Invited Paper)*

Upendra N. Singh, NASA Langley Research Ctr. (United States)

No Abstract Available

9080-3, Session 1

A polarimetric scanning ladar: system development, performance analysis, and field tests

Renu Tripathi, Yury Markushin, Nicholas P. Calvano, Gour S. Pati, Delaware State Univ. (United States)

Laser Detection and Ranging (LADAR) is a widely used optical sensing technology for measuring three-dimensional surface of a target using the intensity and time-of-flight (TOF) information. We have recently developed a polarimetric scanning LADAR which is capable of acquiring polarization signature of the target in addition to acquiring reflectance and geometric information from the target. This system can potentially provide a more powerful mechanism for target classification, particularly while the target is being imaged through various obscuring phenomena such as rain, dust, fog or hidden behind reflective surfaces.

In this presentation, we will discuss the design and operation of a scanning LADAR (scan-LADAR) system developed using a nanosecond pulsed laser, two-dimensional beam-scanning and single linear-mode photodetector. We will present our recent results obtained by conducting the performance analysis and field tests of our scan-LADAR system. Furthermore, we will discuss a polarimetric LADAR system which we have developed explicitly by incorporating automated polarization imaging system (PIS) in the receiving arm of the scan-LADAR system. The PIS architecture uses a combination of two voltage-controlled liquid crystal retarders (LCRs) to perform in-line Stokes polarization imaging of the target. We will present results illustrating target recognition and discrimination in our polarimetric scan-LADAR system using Stokes polarization imaging mechanism.

9080-4, Session 1

A long-distance laser altimeter for terrain relative navigation and spacecraft landing

Diego F. Pierrottet, Coherent Applications, Inc. (United States); Farzin Amzajerdian, Bruce W. Barnes, NASA Langley Research Ctr. (United States)

A high precision laser altimeter was developed under the Autonomous Landing and Hazard Avoidance (ALHAT) project at NASA Langley Research Center. The objective of the laser altimeter is to provide real-time range measurements from over 30 km, to support surface-relative state estimation and navigation during planetary descent for precision landing. The altimeter uses an advanced time-of-arrival receiver that can provide multiple signal-return range measurements from tens of kilometers with 5 cm precision. The transmitter is eye-safe, simplifying operations and testing on earth. The prototype is fully autonomous, and able to withstand the thermal and mechanical stresses experienced during test flights conducted aboard helicopters, fixed-wing aircraft, and Morpheus, a terrestrial rocket-powered vehicle developed by NASA Johnson Space Center. This paper provides an overview of the sensor and presents results obtained during recent field experiments including a helicopter flight test conducted in December 2012 and Morpheus flight test planned for January 2014.

9080-5, Session 1

1541nm GmAPD ladar system

Mary R. Kutteruf, Paul Lebow, U.S. Naval Research Lab. (United States)

The single photon sensitivity of Geiger-mode avalanche photo diodes (GmAPDs) has facilitated the development of LADAR systems that operate at longer stand-off distances, require lower laser pulse powers and are capable of imaging through a partial obscuration. In this paper, we describe a LADAR system which unlike previous system operates at the eye-safe wavelength of 1541 nm. This enhances system covertness and improves haze penetration. The system is comprised of a COTS 1541 nm erbium fiber laser producing 4 ns pulses at 100 kHz to 200 kHz and a COTS camera with a focal plane of 32x32 InGaAs GmAPDs optimized for 1550 nm. Laboratory characterization methodology and results are discussed. We show that accurate modeling of the system response, allows us to achieve a depth resolution which is limited by the width of the camera’s time bin (.25 ns or 1.5 inches) rather than by the duration of the laser pulse (4 ns or 2 ft). In the presents of obscuration, the depth resolution is degraded to 6 inches but

is still significantly better than that dictated by the laser pulse duration. We also show point cloud data generated by the system over an indoor range.

9080-6, Session 1

Mosaïc active imaging: Direct physical modelling, image reconstruction, and experimental assessment

Emmanuelle Thouin, Marie-Thérèse Velluet, Laurent Hespel, Xavier Briottet, Dominique Hamoir, ONERA (France); François Malgouyres, Univ. de Toulouse (France)

Flash active imaging can be used for surveillance or target identification at long range and low visibility conditions. Its principle is based on the illumination of a scene with a pulsed laser. The backscattered signal is then acquired with a high-speed gated camera, sharply synchronized with the emitted pulse. The photons coming back to the sensor are selected according to their round-trip travel time to eliminate the photons back-scattered by the foreground as well by the background. Signal to noise ratio and contrast of the object over the background are then increased in comparison with passive imaging. Even though, range and field of view (FOV) are limited for a given laser power. The new active imaging system presented here aims at overcoming this limitation. It acquires the entire scene with a high-speed scanning laser illumination focused on a limited region, whereas at each scan the full frame active backscattered image is acquired. The whole image is then reconstructed by mosaicking a sequence of all these successive images with various illuminated regions. A first evaluation of the performance of this new system is conducted by using a direct physical model of this so-called « mosaic active imaging ». This End to End model, realistic in terms of turbulence effects (scintillation, beam wandering ...), gives us a sequence of images a synthetic scenes. After describing the end to end model, the reconstruction method will be described. It is based on a total-variation minimization scheme. The performances of this new concept are then compared to those of a conventional flash active camera by using usual metrics (Johnston's criteria, SNR, RMSE, MTF ...). For various mean laser powers, we quantify the gains expected in terms of range and field of view of this new concept. Finally, proofs of concept's tests using an adaptation of an existing flash laser system developed at Onera are presented.

9080-8, Session 2

Design and performance of a fiber array coupled multi-channel photon counting, 3D imaging, airborne lidar system

Genghua Huang, Rong Shu, Libing Hou, Yuxing Ding, Shanghai Institute of Technical Physics (China)

Photon counting lidar has an ultra-high sensitivity which can be hundreds even thousands of times higher than the linear detection lidar. It can significantly increase the system's capability of detection rang and imaging density, saving size and power consumings in airborne or space-borne applications.

Based on Geiger-mode Si avalanche photodiodes (Si-APD), a prototype photon counting lidar which used 8 APDs coupled with a 1?8-pixel fiber array has been made in June, 2011. The experiments with static objects showed that the photon counting lidar could operate in strong solar background with 0.04 receiving photoelectrons on average. Limited by less counting times in moving platforms, the probability of detection and the 3D imaging density would be lower than that in static platforms. In this paper, a latest fiber array coupled multi-channel photon counting, 3D imaging, airborne lidar system is introduced. The correlation range receiver algorithm of photon counting 3D imaging is improved for airborne signal photon events extraction and noise filter. The 3D imaging experiments in the helicopter shows that the false alarm rate is less than 6x10-7, and the correct rate is better than 99.9% with 4 received photoelectrons and 0.7MHz system noise on average.

9080-9, Session 2

16W average power 2μm Thulium fiber laser with one stage MOPA

Wendi Wu, Ting Yu, Qijie Huang, Xiaojin Cheng, Weibiao Chen, Shanghai Institute of Optics and Fine Mechanics (China)

The 2μm laser emitted is eye-safe and in the atmospheric window, which is widely applied in the fields of laser surgery, space optical communication, remote sensing and laser radar etc. Due to its wide gain spectrum from 1.8 to 2.1 μm and high quantum efficiency (the theoretical value is 200%), Tm-doped fiber lasers have attracted increasing interests in recent years. In this work, we will report our recent research on high average power pulsed Tm-doped fiber lasers, which is a master oscillator (seed source) and power amplifier system. The seed source is an acousto-optic Q-switched laser operating at 1.96μm made by ourselves, in which a fiber Brag grating as cavity reflector and the laser material is a 0.6m long 25/250μm (core/cladding diameter) Tm-doped fiber, and the maximum output average power is 2W. Seed laser coupled into power amplifier fiber through a group of lens, the power amplifier consists of a ~3.2m long 25/400μm (core/cladding diameter?PM Tm-doped fiber and a 793nm laser diodes pumped. Finally a nanosecond pulse 1.996μm laser with 16W average power is demonstrated, the full width at half-maximum is about 0.2nm, the repetition rate is 41kHz, and the pulse width is less than 200ns, the a polarization extinction ratio >20 dB. The pulse trains remain stable and the spectrum has no nonlinear effects and broadening, so we could get more output power with more powerful pump source. Such these high power Q-switched Tm-doped fiber lasers can be potential candidates for applications like LIDAR, medicine.

9080-10, Session 2

Laser bathymetry in highly-turbid coastal water using multiply scattered returns

Anthony B. Davis, Jet Propulsion Lab. (United States)

There are compelling reasons, both military and civilian, to harness the ability of drawing reliable bathymetry maps of coastal areas at reasonably high spatial resolution using robust airborne instrumentation. Airborne laser altimetry has revolutionized that field of paramount importance in defense and national security. That highly successful technological development was enabled by high-precision navigation as well as advances in eye-safe pulsed laser technology. The method is simple: knowledge of platform position in space and of orientation of the transmitted pulse—or, at least, of the angular origin of the received pulse—is used to determine with high precision the position in 3D space of the hard target that produced the echo. Even in the presence of vegetation clutter, it is not hard to isolate the ground or artifact's return. Laser bathymetry is a straightforward extension of this technique that accounts for beam refraction at the air-water interface.

However, a fundamental assumption in the methodology is that there is indeed a detectable and distinctive return from the sea floor after the two-way transmission through air and water. It is not rare that coastal water is so turbid (high optical depth), particularly in estuaries, that the direct sea floor echo is lost in noise, including multiply scattered and/or reflected laser light. I will show that there is an alternative physics-based model for bathymetry signals resulting from highly scattered laser light. The model is used to demonstrate that there is a definite signature of sea floor depth in the diffuse light field. Finally, it is proposed that a receiver adapted to this novel measurement is not hard to design.

9080-11, Session 2

Development of scanning laser sensor for underwater 3D measurement

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We have developed laser sensors for underwater exploration, research of ocean-trench earthquake, and so on.

According to our past research, the attenuation coefficient at 532nm is 0.5dB/m in the area which is deeper than the depth of 150m in Sagami Bay, Japan.

Based on this research, we developed the scanning laser sensor for underwater 3D imaging which can detect targets in 20m range at the depth of about 150m.

The features of our system are the following two points.

The first is the coaxial optics. This realizes the wide scanning angle of 120deg (Horizontal) x30deg (Vertical) with the compact size of ϕ25cmx60cm. The size is capable of mounting on underwater vehicles.

The second is the function of the sensitivity time control (STC), in which the gain of the receiver is increased according to the time of flight. Because of this control, we can detect a small signal by suppressing unwanted signals scattered by marine snows, and so on. Additionally, time slope of STC is variable, therefore the system is able to adapt to underwater environmental variation.

We have demonstrated the system performance in underwater environments with a step-by-step approach.

First, we tested basic performance in the pool, and confirmed ranging targets at the distance of 20m with the accuracy of 3cm.

After that, we tested the system in the shallow sea area, and performed 3D imaging of several objects.

In addition, the system is mounted on the autonomous underwater vehicle “Otohime” developed by JAMSTEC (Japan Agency for Marine-earth Science and TEChnology), and demonstrated seabed mapping in the deep sea area (depth ~100m in Sagami Bay).

In this paper, we introduce our system concepts and the above mentioned demonstrations.

9080-12, Session 2

Coherent Doppler lidar backscattered signal power validation against direct detection

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Backscattered signal power of a coherent Doppler Lidar (CDL) system for wind sensing was validated against that of a direct detection Lidar system. In coherent detection, the received signal power depends on the overlap integral between the backscattered and local oscillator fields. This overlap is influenced by both the geometric optics considerations of the antenna system and the loss of coherence of the backscattered field caused by propagation through atmospheric aerosol scattering and refractive turbulence. In this study, we present the analysis of range correcting of CDL backscattered signal power and report CDL wind measurements with signal power validation against direct detection measurements.

9080-13, Session 2

Outward atmospheric scintillation effects and inward atmospheric scintillation effects comparisons for direct detection ladar applications

Douglas G. Youmans, SPARTA, Inc. (United States)

Atmospheric scintillation affects laser radar imaging through atmospheric turbulence both on the outward path and on the return path. We expand last year’s paper in deriving the outward scintillation index analytically in more detail and comparing to Monte Carlo propagation code results. Likewise, we derive the inward scintillation index analytically in more detail and compare to plane-wave Monte Carlo propagation code results. The magnitude of the two effects for various geometries and turbulence levels will be examined.

Combining the two scintillation indices with laser hardbody-target speckle, as measured on the focal plane array at the focus of a lens, will be briefly reviewed following last year’s paper. Recent modeling advances in this area will be discussed briefly.

9080-14, Session 2

High-fidelity flash lidar model development

Glenn D. Hines, NASA Langley Research Ctr. (United States); Diego F. Pierrottet, Coherent Applications, Inc. (United States); Farzin Amzajerdian, NASA Langley Research Ctr. (United States)

NASA’s Autonomous Landing and Hazard Avoidance Technologies (ALHAT) project is currently developing the critical technologies to safely and precisely navigate and land crew, cargo and robotic spacecraft vehicles on and around planetary bodies. One key element of this project is a high-fidelity Flash lidar sensor that can generate three-dimensional (3-D) images of the planetary surface. These images are processed with hazard detection and avoidance (HDA) and hazard relative navigation (HRN) algorithms, and then subsequently ingested by the Guidance, Navigation and Control (GN&C) subsystem, which uses them to generate an optimal navigation solution.

A complex, high fidelity model of the Flash lidar was developed in order to evaluate the performance of the sensor and its interaction with the interfacing ALHAT components on space vehicles with different configurations and under different flight trajectories. The model contains a parameterized, general approach to Flash lidar detection and reflects physical attributes such as range and electronic noise sources, and laser pulse temporal and spatial profiles. It also provides the realistic interaction of the laser pulse with terrain features that may include varying albedo, boulders, craters, slopes, and shadows. This paper gives a description of the Flash lidar model and presents some the results from the lidar operation under different scenarios.

9080-16, Session 2

Doppler lidar system design via interdisciplinary design concept at NASA Langley Research Center

Charles M. Boyer, NASA Langley Research Ctr. (United States); Trevor P. Jackson, Old Dominion Univ. (United States); Jeffrey Y. Beyon, Larry B. Petway, NASA Langley Research Ctr. (United States)

Optimized designs of the Navigation Doppler Lidar (NDL) instrument for Autonomous Landing Hazard Avoidance Technology (ALHAT) were accomplished via Interdisciplinary Design Concept (IDEC) at NASA Langley Research Center during the summer of 2013. Three branches in Engineering Directorate and three students were involved in this joint task through the NASA Langley Aerospace Research Summer Scholars (LARSS) Program.

Laser Remote Sensing Branch (LRSB), Mechanical Systems Branch (MSB), and Structural and Thermal Systems Branch (STSB) were engaged to achieve optimal designs through iterative and interactive collaborative design processes. A preliminary design iteration was able to reduce the power consumption, mass, and footprint by removing redundant components and replacing inefficient components with more efficient ones. A second design iteration reduced volume and mass by replacing bulky components with excessive performance with smaller components custom-designed for the power system. Mechanical placement collaboration reduced potential electromagnetic interference (EMI). Through application of newly selected electrical components and thermal analysis data, a total electronic chassis redesign was accomplished. Use of an innovative forced convection tunnel heat sink was employed to meet and exceed project requirements for cooling, mass reduction, and volume reduction. Functionality was a key concern to make efficient use of airflow, and accessibility was also imperative to allow for servicing of chassis internals. The collaborative process provided for accelerated design maturation with substantiated function.

9080-17, Session 3

Improving waveform lidar processing: Toward robust deconvolution of signals for improved structural assessments

Kerry Cawse-Nicholson, Jan van Aardt, Shea Hagstrom, Paul Romanczyk, Rochester Institute of Technology (United States); Crystal Schaaf, Univ. of Massachusetts Boston (United States); Alan Strahler, Zhan Li, Boston Univ. (United States); Keith Krause, NEON, Inc. (United States)

In a typical waveform light detection and ranging (lidar) system, the received pulse is a convolution of the system impulse response, the outgoing pulse, and the underlying signal representing actual target interactions. Deconvolution is the process of removing the contribution of the system impulse response and outgoing pulse from the received signal, so that the true interactions may be seen. In many examples, deconvolution has been shown to expose fine structure within the waveform, which may be used to improve accuracy when estimating the vertical location of certain features. For instance, the exact location of the ground may be more accurately determined by separating the response of the ground from that of understory vegetation or vegetative ground cover. However, in order for the deconvolution to be successful, the impulse response and outgoing pulse must be known, and many deconvolution methods are sensitive to small errors in the estimation of these inputs. In this study, we propose a deconvolution method that uses a flat target response in place of the impulse response and outgoing pulse. This method is validated using waveform lidar data acquired by the National Ecological Observatory Network (NEON) over Harvard Forest, MA in August 2012. During a coincidental collaborative fieldwork campaign, the heights of 69 trees within a 100m x 100m site were recorded. These tree heights are used to validate the improvement in feature detection within the waveform after a deconvolution has been applied. Detailed results will be presented at the conference.

9080-18, Session 3

Online waveform processing versus full waveform analysis for demanding target situations

Martin Pfennigbauer, Andreas Ullrich, RIEGL Laser Measurement Systems GmbH (Austria)

RIEGL LIDAR instruments are based on echo digitization and provide point cloud data by online waveform processing or full waveform data for external full waveform analysis or both. The advantages of online waveform processing of being fast and highly accurate for most typical target situation are made up by full waveform processing for demanding echo signal shapes when employing sophisticated algorithms. It is investigated how novel advanced online waveform processing techniques can compete even with optimized full waveform analysis and where the limitations are. Specific real-life waveforms are analyzed concurrently and the results are compared and evaluated.

9080-19, Session 3

Range resolution improvement of eyesafe ladar testbed (ELT) measurements using sparse signal deconvolution

Scott E. Budge, Jacob H. Gunther, Utah State Univ. (United States)

The Eyesafe Ladar Test-bed (ELT) is a experimental ladar system with the capability of digitizing return laser pulse waveforms at 2 GHz. These waveforms can then be exploited off-line in the laboratory to develop signal processing techniques for noise reduction, range resolution improvement, and range discrimination between two surfaces of similar range interrogated by a single laser pulse.

This paper presents a method to improve the range discrimination of the ladar system by deconvolution using sparse signal techniques. Ladar returns from sloped surfaces or surfaces of similar ranges consist of a small number of overlapping pulses. The exact number of overlapping pulses and the delays and amplitudes of the pulses are unknown. Deconvolution aims to estimate these parameters.

We exploit the sparsity of ladar returns and solve the deconvolution problem in two steps. The first step is to estimate a point target response using a database of measured calibration data. This basic target response is used to construct a dictionary of target responses with different delays/ranges. Using this dictionary ladar returns from a wide variety of surface configurations can be synthesized by taking linear combinations. A sparse linear combination matches the physical reality that ladar returns consist of the overlapping of only a few pulses. The dictionary construction process is a pre-processing step that is performed only once.

The deconvolution step is performed by minimizing the error between the measured ladar return and the dictionary model while constraining the coefficient vector to be sparse. Other constraints such as the non-negativity of the coefficients are also applied. The results of the proposed technique are presented in the paper and are shown to compare favorably with other deconvolution techniques. We report results on real and simulated datasets.

9080-21, Session 3

High-speed on-board data processing for science instruments

Jeffrey Y. Beyon, Tak-Kwong Ng, Bing Lin, Yongxiang Hu, Wallace Harrison, NASA Langley Research Ctr. (United States)

A new development of on-board data processing platform has been in progress at NASA Langley Research Center since April, 2012, and the overall review of such work is presented in this paper. The project is called High-Speed On-Board Data Processing for Science Instruments (HOPS) and focuses on an air/space-borne high-speed scalable data processing platform for three particular National Research Council's Decadal Survey missions such as Active Sensing of CO2 Emissions over Nights, Days, and Seasons (ASCENDS), Aerosol-Cloud-Ecosystems (ACE), and Doppler Aerosol Wind Lidar (DAWN) 3-D Winds. HOPS utilizes advanced general purpose computing with Field Programmable Gate Array (FPGA) based algorithm implementation techniques. The significance of HOPS is to enable high speed on-board data processing for current and future science missions with its reconfigurable and scalable data processing platform. A single HOPS processing board is expected to provide approximately 66 times faster data processing speed for ASCENDS, more than 70% reduction in both power and weight, and about two orders of cost reduction compared to the state-of-the-art (SOA) on-board data processing system. Such benchmark predictions are based on the data when HOPS was originally

proposed in August, 2011. The details of these improvement measures are also presented. The two facets of HOPS development are identifying the most computationally intensive algorithm segments of each mission and implementing them in a FPGA-based data processing board. A general introduction of such facets is also the purpose of this paper.

9080-22, Session 3

Incoherent pulse compression in laser range finder

Daniel Grodensky, Daniel Kravitz, Bar-Ilan Univ. (Israel); Nadav Levanon, Tel Aviv Univ. (Israel); Avinoam Zadok, Bar-Ilan Univ. (Israel)

The effective compression of encoded pulse sequences usually requires phase coding, whereas intensity-based coding leads to inferior performance. The measurement of phase in a photonic system, however, involves complicated coherent receivers. Here, a method for the effective compression of a coded pulse sequence in an incoherent laser range finder, employing simple direct detection, is proposed and demonstrated experimentally [1, 2]. Binary phase sequences are converted to a unipolar intensity modulation through a position-coding algorithm, and then used to modulate the laser ranging source. The reflected echoes undergo simple direct detection, followed by correlation with a bipolar reference sequence that is digitally stored at the receiver. The received filtered sequence closely replicates the effective sidelobe suppression of the original phase code.

The principle was experimentally implemented using a 1112 bits-long maximum peak-to-sidelobe ratio (MPSL) sequence [2], and 832 bits-long complementary code pairs. A peak-to-sidelobe ratio of 46 dB was experimentally obtained following compression. Ranging resolution was 3 cm. The range to a target could be measured in the presence of additive noise, at signal-to-noise ratios as low as -20 dB [2]. This noise tolerance can be leveraged towards a longer measurement range, reduced probability of inctercept, lower launch power and energy consumption, smaller apertures and improved operation at unfavorable atmospheric conditions.

References

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9080-23, Session 4

Algorithm for detecting important changes in LIDAR point clouds

Dmitriy Korchev, Yuri Owechko, HRL Labs., LLC (United States)

Protection of bases in hostile environments is a very critical part of military and civilian operations that requires a significant amount of security personnel to be deployed around the clock. Any electronic change detection system for detection of threats must have high probability of detection and low false alarm rates to be useful in presence of natural motion of trees and vegetation due to wind. We propose a 3D change detection system based on a LIDAR sensor that can reliably and robustly detect threats and intrusions in different environments including surrounding trees, vegetation, and other natural landscape features. Our LIDAR processing algorithm finds human activity and human-caused changes not only in open spaces but also in heavy vegetated areas hidden from direct observation by 2D imaging sensors. The algorithm processes a sequence of point clouds called frames. Every 3D frame is mapped into a 2D horizontal rectangular grid. Each cell of this grid is processed to calculate the distribution of the points mapped into it. The spatial differences are detected by analyzing the differences in distributions of the corresponding cells that belong to different frames

9080-24, Session 4

Improved registration for 3D image creation using multiple texel images and incorporating low-cost GPS/INS measurements

Scott E. Budge, Xuan Xie, Utah State Univ. (United States)

The creation of 3D imagery is an important topic in remote sensing. Several methods have been developed to create 3D images from fused ladar and digital images, known as texel images. These methods have the advantage of using both the 3D ladar information and the 2D digital imagery directly, since texel images are fused during data acquisition. A weakness of these methods is that they are dependent on correlating feature points in the digital images. This can be difficult when image perspectives are significantly different, leading to low correlation values between matching feature points.

This paper presents a method to improve the quality of 3D images created using existing approaches that register multiple texel images. The proposed method incorporates relatively low accuracy measurements of the position and attitude of the texel camera from a low-cost GPS/INS into the registration process. This information can improve the accuracy and robustness of the registered texel images over methods based on point-cloud merging or image registration alone. In addition, the dependence on feature point correlation is significantly decreased. Examples illustrate the value of this method for large image perspective differences.

9080-25, Session 4

Estimating sampling completeness of lidar datasets using voxel-based geometry

Shea Hagstrom, David Messinger, Katie N. Salvaggio, Rochester Institute of Technology (United States)

Advances in LIDAR technology have made sub-meter resolutions from airborne instruments possible, enabling quick capture of fine 3D details over large areas. During collection, occluding objects may prevent a laser pulse from reaching regions where overlapping geometry is present, such as under tree canopies. This is particularly true given the near-nadir angles typically used by airborne LIDAR, since the limited number of unique angles does not ensure that all surfaces can be sensed. These missed surface detections decrease the overall quality of a dataset, but are not normally quantified due to a lack of ground-truth. Using information that is normally discarded about the LIDAR instrument position, we show how these unsampled regions can be identified by tracing the path of each laser pulse. A voxel representation provides the framework for computing the necessary statistics, and also allows for correct representations of overlapping geometry in complex environments. Based on this novel unsampled information we show how the fraction of total surfaces sensed and not sensed by the LIDAR can be estimated, giving a measurement of how completely all surfaces are sampled. Results are demonstrated for multiple real-world datasets, as well as the effects of voxel resolution and data density on the sampling completeness metric.

9080-26, Session 4

Graph segmentation and point-based features for SVM bare earth alassification in lidar data

Nicholas S. Shorter, Anthony O. Smith, Philip Smith, Kristian Damkjer, Mark D. Rahmes, Harris Corp. (United States)

A novel approach using a support vector machine (SVM) is proposed to classify bare earth points in LiDAR point clouds. Using graph based segmentation, the LiDAR point cloud is segmented into a set of topological components. Several features establishing relationships from those components to their neighboring components are formulated. In addition

to the component features, several point based features based on their relationship to other points are also formulated. The SVM is then trained on both the point based and segment based features to establish a model for classification of bare earth and non bare earth points. Qualitative results are presented for data collected from both Geiger mode and Linear mode LiDAR sensors, data collected over a variety of different landscapes, and data containing a plethora of different building structures. Quantitative results are presented for the algorithm's performance when evaluated on the ISPRS data set. Despite the data being captured from different sensors, and collected from scenes with different terrain types and building structures, the results shown were processed with no parameter changes. Furthermore, a confidence value is returned indicating how well the unforeseen data fits the SVM's trained model for bare earth recognition.

9080-28, Session 5

Uncertainty assessment and probabilistic change detection using terrestrial and airborne lidar

Andre Jalobeanu, Angela M. Kim, Scott C. Runyon, Richard C. Olsen, Fred A. Kruse, Naval Postgraduate School (United States)

Change detection using remote sensing has become increasingly important for characterization of natural disasters. Pre- and post-event LiDAR data can be used to identify and quantify changes. The main challenge consists of producing reliable change maps that are robust to differences in collection conditions, free of processing artifacts, and that take into account various sources of uncertainty such as different point densities, different acquisition geometries, georeferencing errors and geometric discrepancies. We present a novel technique that accounts for these sources of uncertainty, and enables the creation of statistically significant change detection maps. The technique makes use of Bayesian inference to estimate uncertainty maps from LiDAR point clouds. Incorporation of uncertainties enables a change detection that is robust to noise due to ranging, position and attitude errors, as well as "roughness" in vegetation scans. Validation of the method was done by use of small-scale models scanned with a terrestrial LiDAR in a laboratory setting. The method was then applied to two airborne collects of the Monterey Peninsula, California acquired in 2011 and 2012. These data have significantly different point densities (8 vs. 40 pts/m2) and some misregistration errors. A new point cloud registration technique was developed to correct systematic shifts due to GPS and INS errors. Sparse changes were detected and interpreted mostly as construction and natural landscape evolution.

9080-29, Session 5

Lidar change detection using small-scale building models

Angela M. Kim, Scott C. Runyon, Andre Jalobeanu, Chelsea H. Esterline, Fred A. Kruse, Naval Postgraduate School (United States)

Terrestrial LiDAR scans of small-scale building models collected with a Faro Focus 3D and a Riegl VZ-400 were used to investigate point-to-point and model-to-model LiDAR change detection. LiDAR data were scaled, decimated, and georegistered to mimic real-world airborne collects. Two physical building models were used to explore various aspects of the change detection process. The first model was a small-scale representation of the Naval Postgraduate School campus in Monterey, CA, constructed from Lego blocks and scanned in a laboratory setting using both the Faro and Riegl. The second model consisted of large cardboard boxes placed outdoors and scanned from rooftops of adjacent buildings using the Riegl. A point-to-point change detection scheme was applied directly to the point-cloud datasets. In the model-to-model change detection, changes were compared between Digital Surface Models (DSMs). The use of physical models allowed analysis of effects of changes in scanner and scanning geometry; and performance of the change detection methods on different types of changes, including building collapse or subsistence, construction, and shifts in location. Results indicate that at low false-alarm rates, the point-to-point method outperforms the model-to-model method, while the model-to-model method is less sensitive to differences in collection geometries and differences between the sensors.

9080-30, Session 5

Correlation between lidar-derived intensity and passive optical imagery

Jeremy P. Metcalf, Angela M. Kim, Fred A. Kruse, Naval Postgraduate School (United States)

When LiDAR data are collected, the intensity information is recorded for each return, and can be used to produce an image resembling those acquired by passive sensors. This research evaluated LiDAR intensity data to determine its potential for use as baseline imagery where optical imagery are otherwise unavailable. Two aerial LiDAR datasets collected at different point densities and laser wavelengths were gridded and compared with optical imagery. Optech Orion C200 laser data were compared with a corresponding 1500nm spectral band from the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS). Optech ALTM Gemini LiDAR data collected at 1064 nm were compared to the WorldView-2 (WV-2) 949 – 1043 nm NIR2 band. Intensity images were georegistered and spatially resampled to match the optical data. The Pearson Product Moment correlation coefficient was calculated between datasets to determine similarity. Comparison for the full LiDAR datasets yielded correlation coefficients of approximately 0.5. Because LiDAR returns from vegetation are known to be highly variable, a Normalized Difference Vegetation Index (NDVI) was calculated utilizing the optical imagery, and intensity and optical imagery were separated into vegetation and non-vegetation categories. Comparison of the LiDAR intensity for non-vegetated areas to the optical imagery yielded coefficients greater than 0.9. The effect of LiDAR point density on the results was also examined by decimating the LiDAR returns by 50 and 75%. The lower point density LiDAR data respectively exhibited correlation coefficients of 0.7737 and 0.7786. These results demonstrate that LiDAR intensity data may be useful in simulating optical imagery where only LiDAR is available.

9080-31, Session 5

A calibration method of the multi-channel imaging lidar

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We design a kind of imaging LiDAR with sixteen channels, which consists of a fiber laser source, dual scanning galvanometers, range measurement circuits and information processing circuits etc. The image LiDAR provides sixteen range measurements for one laser shot and the distance accuracy of each channel is about 4cm. This paper provides a calibrate method to correct point cloud images captured with the multi-channel LiDAR. The method needs to construct different slanted planes to cover the imaging field, and establish precise plane equations in the known ground coordinates, then fit planes with point clouds data and calculate correction parameters of all channels through the error model. The image accuracy is better than 5cm processed by this calibration method.

9080-32, Session 6

Using an eyesafe military laser range finder for atmospheric sensing

Ove Steinvall, Rolf Persson, Folke Berglund, Ove K. S. Gustafsson, Swedish Defence Research Agency (Sweden)

Laser Rangefinders are well established components in various electro-

optical fire control systems. Recent range finders are often operating at eye safe wavelengths around 1.5 μm which extend their utility. One such extension is the use of the sensor for atmospheric sensing based on the measured backscatter signal.

The present paper investigates the use of a eye-safe laser rangefinder at 1.5 μm to obtain information on atmospheric attenuation at various paths in the atmosphere. This knowledge can in turn be used in combination with atmospheric and target/background models to estimate the performance of other EO sensors like TV and thermal imagers beside the laser range finder itself. Such information can be of great value both for estimating own sensor capabilities at a given moment as well as estimating the threat capability. One obvious example is ship defense where it is difficult to obtain visibility along a variable atmosphere especially in darkness.

The paper will describe the experimental equipment and the results from measurements of atmospheric backscatter along various atmospheric paths. The backscatter curve is used to evaluate the extinction. This extinction values are compared with those deduced from a point visibility meter and from echo measurements against two similar nets positioned at 2 ranges from the sensor. The results indicated a good correspondence between these results. Finally the results are illustrated in a system perspective by estimating the performance for thermal IR and other EO sensors.

9080-33, Session 6

Development of a fluorescence lidar for measurement of atmospheric formaldehyde

Anand Radhakrishnan Mylapore, MassTech Inc. (United States); Mikhail Yakshin, Alexander Achey, In Heon Hwang, Sangwoo Lee, Nikhil Mehta, Geary K. Schwemmer, Coorg R. Prasad, Science and Engineering Services, Inc. (United States); Thomas F. Hanisco, NASA Goddard Space Flight Ctr. (United States)

Formaldehyde (H2CO) is an important trace species that plays a key role in atmospheric chemistry, which affects the climate and atmospheric pollution. Its importance is well recognized and several spaceborne instruments / missions such as the OMI (Aura Ozone Monitoring Instrument), TEMPO (Tropospheric Emissions Monitoring of Pollution), GEO-CAPE (GEOstationary Coastal and Air Pollution Events), and GACM (Global Atmospheric Composition Mission) for measuring H2CO are in various stages of implementation. We are developing a fluorescence lidar for tropospheric H2CO concentration profiling that complements spaceborne measurements. H2CO has a strong absorption band in the 352 - 357nm region and fluoresces strongly in the 390 – 500nm region. Earlier, we had demonstrated range-resolved, nighttime, ppb-level H2CO measurements at 1km range, with a breadboard differential fluorescence lidar using a commercial frequency-tripled Nd:YAG laser (354.7 nm) whose spectral linewidth (0.02nm) covered multiple absorption lines. Here, we describe a prototype lidar system for providing more than an order of magnitude higher sensitivity (~0.1ppb) for H2CO profiles throughout the troposphere. Higher sensitivity is achieved by: 1. injection seeding the Nd:YAG laser with a single longitudinal mode 1064nm diode laser to reduce its linewidth below the absorption linewidth (0.07cm-1 at 150torr pressure) and tuning its wavelength to the center of a strong absorption line; and 2. increasing the fluorescence signal using a multi-linepass filter whose pass-bands are aligned to the multiple fluorescence peaks of H2CO. A photo-acoustic absorption cell that measures the 355nm H2CO absorption is utilized for tuning and locking the seeder wavelength to the center of absorption line. We present the spectral characteristics of the laser when its wavelength is toggled between line center and line wing and the measurements of H2CO by the lidar.

9080-34, Session 6

A three-beam aerosol backscatter correlation lidar for 3-component wind profiling

Anand Radhakrishnan Mylapore, Konstantin Novoselov, MassTech Inc. (United States); Sangwoo Lee, Mikhail Yakshin, Alexander Achey, In Heon Hwang, Nikhil Mehta, Geary K. Schwemmer, Coorg R. Prasad, Science and Engineering Services, Inc. (United States); Narasimha S. Prasad, NASA Langley Research Ctr. (United States)

In this paper, we describe the development of a multi-beam elastic lidar that utilizes aerosol backscatter correlation to generate three-component wind profiles used for detecting and tracking aircraft wake vortices; turbulence intensity and wind shear profiles. High-resolution time-resolved wind information can currently be obtained with ultrasonic or hot-wire anemometers suitable for local point measurements, or with Doppler wind lidars that only measure line-of-sight wind speeds and have to be scanned over large measurement cone angles for obtaining three-component winds. By tracking the motion of aerosol structures along and between three near-parallel laser beams, our lidar obtains three-component wind speed profiles along the field of view (FOV) of the lidar beams. Our prototype lidar wind profiler (LWP) has three 8-inch transceiver modules placed in a near-parallel configuration on a two-axis pan-tilt scanner to provide winds up to 2km. Passively q-switched near-infrared (1030nm) Yb:YAG lasers generate 12 - 18ns wide pulses at high repetition rate (about 10KHz) that are expanded and attenuated to eye-safe levels. Sensitive low noise detection is achieved even in daytime using a narrow FOV receiver, together with narrowband interference filters and single photon-counting Geiger-mode Si detectors. A multi-channel scaler retrieves the lidar return with 7.8ns bins (~1.2m spatial resolution) and stores accumulated counts once every 50ms (20 profiles/sec). We adapted optical flow algorithms to obtain the movement of aerosol structures between the beams. We validated the LWP prototype using sonic anemometer measurements for comparison. A higher-resolution, short-range version of this instrument suitable for helicopter downwash measurement is under development.

9080-35, Session 6

Laser remote sensing of species concentrations and dynamical processes

C. Russell Philbrick, Hans D. Hallen, North Carolina State Univ. (United States)

A review of recently developed lidar techniques shows present capabilities can: (1) measure atmospheric concentrations of most major and several minor molecular species using Raman scattering and DIAL techniques, (2) detect and measure concentrations of certain trace level species, (3) characterize active dynamical processes in the troposphere based upon the redistribution of water vapor, and (4) describe interesting thermodynamic properties based upon rotational Raman temperature profiles, multi-wavelength aerosol distributions, and changes in the phase states of water. Advances in lasers and detectors have extended the range of wavelengths available thru the ultraviolet, visible, and infrared spectrum by using tunable OPO techniques and supercontinuum broad spectrum lasers. While reviewing these prior studies, several applications for the technology are suggested and extensions of the techniques proposed for future investigations. In particular, the extension of OPO tunable laser sources into the ultraviolet region has opened opportunities to use resonance Raman techniques to provide increased selectivity and signal for certain molecular species, such as ring-hydrocarbons. The developments in supercontinuum lasers and infrared detectors enable concentration measurements that use of all of the lines in a band-head to improve the measurement statistical accuracy and separate any confounding and interfering species.

9080-36, Session 6

Tunable laser remote sensing for aerosol species identification

Shupeng Niu, C. Russell Philbrick, Hans D. Hallen, North Carolina State Univ. (United States)

Laser based techniques that observe the scattering profile from an aerosol

distribution can be used to measure the particle size distribution, and in some cases the index of refraction. It is of great interest to be able to identify the species that makes up the aerosol using remote sensing. This provides rapid feedback and much higher temporal response than collection of particles followed by later chemical analysis. We show that measurements of the light scattered by the aerosols at a single angle in the aureole region provide a signature for the species as the wavelength of the incident laser is tuned across an absorption feature of the material. The choice of angle eliminates particle size and shape dependent effects such as the particle scattering resonances often observed in Mie calculations. These resonances depend upon measurement angle, incident wavelength, and the particle size. They occur at angles larger than those of the aureole region. The aureole is also largely independent of particle shape for eccentricity up to ~2. Advances in lasers and detectors have extended the range of wavelengths available thru the ultraviolet, visible, and infrared spectrum by using tunable OPO techniques and supercontinuum broad spectrum lasers. These systems permit multiple wavelength operation in spectral regions of interest for many compounds, making the proposed technique practical.

9080-37, Session 6

Offshore wind measurements using Doppler aerosol wind lidar (DAWN) at NASA Langley Research Center

Jeffrey Y. Beyon, Grady J. Koch, Michael J. Kavaya, NASA Langley Research Ctr. (United States)

The latest flight demonstration of Doppler Aerosol Wind Lidar (DAWN) at NASA Langley Research Center (LaRC) is presented. The goal of the campaign was to demonstrate the improvement of DAWN system since the previous flight campaign in 2012 and the capabilities of DAWN and the latest airborne wind profiling algorithm APOLO (Airborne Wind Profiling Algorithm for Doppler Wind Lidar) developed at LaRC. The comparisons of APOLO and another algorithm are discussed utilizing two and five line-of-sights (LOSs), respectively. Wind parameters from DAWN were compared with ground-based radar measurements for validation purposes. The campaign period was June – July in 2013 and the flight altitude was 8 km in inland toward Charlotte, NC, and offshores in Virginia Beach, VA and Ocean City, MD. The DAWN system was integrated into a UC12B with two operators onboard during the campaign.

9080-38, Session 6

Tail clipping of TE-CO_2 laser pulse using gas breakdown technique for high-resolution chemical plume detection

Taieb Gasmi, Saint Louis Univ.- Madrid Campus (Spain)

High stability and energy-efficient TE–CO2 laser pulse clipper using gas breakdown techniques for high spatial resolution chemical plume detection is presented. The most dominant time constant, attributed to TE–CO2 unclipped laser pulses, is its nitrogen tail which extends for several microseconds beyond the gain-switched spike. Near-field scattered signal, produced by unclipped laser pulses, interferes with the weak signal backscattered from the long range and far field atmospheric aerosols which ultimately degrades the range resolution of LIDARS to some hundreds of meters. Short laser pulses can be obtained by various techniques such as mode locking, free induction decay, pulse slicing with electro-optic switched. However, output pulses from those devices require further amplification for any useful application due to their very low energy content. This problem is circumvented in this work by the use of a plasma clipper that achieves high range-resolved remote sensing in the atmosphere. Complete extinction of the nitrogen tail is obtained at pressures extending from 375 up to 1500 Torr for nitrogen and argon gases and approximately five orders of magnitudes for helium. Optimum pressures for helium, argon, and nitrogen, that provide the best stability of the transmitted energy and complete extinction of the nitrogen tail, are identified. Excellent range resolutions can be achieved with TE–CO2 laser-based LIDAR systems. Clipped laser pulses are also field tested.

9080-53, Session Posters-Tuesday

Detecting binary non-return-to-zero data in free-space optical communication systems using FPGAs

Vy Bui, Lan Tran, Esam El-Araby, Nader Namazi, The Catholic Univ. of America (United States)

A new method was presented in [1] and [2] to perform bit synchronization and detection of binary Non-Return-to-Zero (NRZ) data from a free-space optical (FSO) communication link. It was shown that the Haar wavelet is an excellent choice for this purpose. The center frequency of this filter is a function of the scale and could be adjusted to adapt to the variation of the channel. The output of the filter is zero-mean and is closely related to the derivative of the binary data. The filter has a linear phase; therefore, its output is used for synchronization and detection of the data.

In this paper, we leverage our previous work [1] in which we investigated the effects of atmospheric turbulence on an FSO that uses binary NRZ data with no modulation. We propose to provide a hardware prototype to the concepts introduced in [1]. The applicability of these concepts will be demonstrated through providing a real-time prototype using one of the state-of-the-art reconfigurable hardware, namely FPGA, and highly productive high-level design tools such as System Generator for DSP from Xilinx.

References

[1] N. M. Namazi, R. Burris, C. Conner, G. Gilbreath, "Synchronization and Detection of Binary Data in Free-Space Optical Communication Systems using Haar Wavelet Transformation", Optical Engineering, Vol. 45, No. 1, January 2006.

[2] N. M. Namazi, R. Burris, G. Gilbreath, "Analytical Approach to Calculation of Probability of Bit Error and Optimum Thresholds in Free-Space Optical Communication", Optical Engineering, Vol. 46, No. 2, February 2007.

9080-39, Session 7

Scintillation fluctuations of laser beam propagation in strong atmospheric turbulence

Joseph T. Coffaro, Michael G. Panich, Larry Andrews, Univ. of Central Florida (United States); Ronald Phillips, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

The purpose of this research is to experimentally verify mathematical models developed by Dr. Larry Andrews for scintillation fluctuations from weak to strong atmospheric turbulence regions. Propagation range lengths were varied to confirm the generated mathematical scintillation curves. In order to confirm the range dependent scintillation curve, measurements for transmitted beam size, received beam size, cross wind, and the refractive index structure parameter (Cn2) data were taken at various ranges. A Laser was propagated an assortment of distances along the 1 kilometer range at the TISTEF facility located on Kennedy Space Center. Data was taken and analyzed using a quantity of 1,2,3 and 4 detectors. The material presented in this paper outlines the verification and validation of the theoretical scintillation curve, and steps to improve the scintillation fluctuation effects on the laser beam through additional detectors. Experimental data was post processed and analyzed for scintillation and fading effects. These research results demonstrated the benefit of additional detectors and validated a mathematical model that can be scaled for uses in a verity of communications or defense applications. Scintillation is a problem faced by every free space laser system and the verification of an accurate mathematical model to simulate these effects has strong implication across the industry.

9080-40, Session 7

Internal anisotropy of the turbulent scintillations

Mikhail I. Charnotskii, National Oceanic and Atmospheric Administration (United States)

We introduce a new concept of the Internal Anisotropy (IA) for the homogeneous and isotropic random fields. IA reflects the hidden structures that can exist in the samples of the random field, and are not revealed by the simplest, single and two-point statistical moments. There is presently no established theory of the IA, and no quantitative metrics of IA are available. It is understood, however, that IA cannot be present in any stationary isotropic Gaussian random field, or any single-point transformations of it. We start with illustrating the IA concept on a simple toy model of two-dimensional random field, and show that IA can affect the third and higher-order multipoint statistical moments. We proceed to generate samples of the random irradiance distributions for the plane wave passed through a phase screen with the quasi-Kolmogorov statistics. Visual evaluation of the samples suggests the presence of the IA in the irradiance samples. The statistical analysis reveals that the three-point third moment of irradiance exhibit the features consistent with the IA, especially in the focusing conditions. We also present the asymptotic analytical calculations of the third moment of the plane wave irradiance that indicate the presence of the IA, which is more pronounced under focusing conditions. IA of scintillations in the focusing regime can be explained by the higher probability of the appearance of astigmatic lenses than the spherical ones as a portion of the random phase screen, causing the random point spread function to be elongated in one direction.

9080-41, Session 7

Simulation of partially spatially coherent laser beam and comparison with field test for both terrestrial and maritime environments

Nelofar Mosavi, Johns Hopkins Univ. Applied Physics Lab. (United States); Curtis R. Menyuk, Univ. of Maryland, Baltimore County (United States); Brian S. Marks, Bradley G. Boone, Johns Hopkins Univ. Applied Physics Lab. (United States); Charles Nelson, U.S. Naval Academy (United States)

Free-space optical communication links support both commercial and military applications due to their high-bandwidth and high directivity, which makes them hard to detect, intercept, and jam.

These links however, have some drawbacks as well. A laser beam propagating in free space can undergo significant random intensity fluctuations due to turbulence along the propagation path. A coherent beam (CB) becomes partially coherent when it propagates in atmospheric turbulence, especially in strong turbulence. The theory developed by Banach and recently by Ricklin and Davidson on the use of a spatially partially coherent source beam as applied to atmospheric turbulence for the communication channel shows that it is possible to decrease the receiver scintillations in some cases by reducing the spatial coherence of the beam and in that way improve the bit error ratio (BER).

In this paper, we present simulations of partially spatially coherent infra-red and visible laser beams (PCB) with different degrees of spatial coherence through a turbulent atmosphere. The results have been compared to both maritime and terrestrial field test data that was collected near the US Naval Academy. We study the effect on the receiver scintillation as the spatial coherence varies, since optimization reduction of the scintillations through control of the degree of spatial coherence can lead to improvements of the BER. Additionally, we compare the probability density function (PDF) of the intensity for simulation in the simulation to what is observed in the field test data, since the PDF of the intensity for a given detector is critical for estimation of the fade statistics of an optical signal.

9080-42, Session 7

Adaptive laser beam focusing through turbulence in conditions of reciprocity violation

Anatoliy Khizhnyak, Vladimir B. Markov, Advanced Systems & Technologies, Inc. (United States)

Degradation of the laser beam quality at its propagation in turbulent regime remains a major problem for many applications. Mitigation of turbulent effects is achieved typically by using adaptive optics systems with their performance based on the reciprocity principle. The latter one states that two counter-propagating waves are reciprocal when their complex amplitudes are identical in each cross-section along the range. When propagating in the linear inhomogeneous medium, parity of these complex amplitudes in a single cross-section of the range means they are reciprocal. For a practical realization of this principle the adaptive optics system should guaranty the coincidence of these two waves at the pupil plane of the receiving/transmitting aperture. However in various propagation scenarios a complete satisfaction of reciprocal conditions for the beacon and outgoing waves is difficult to satisfy, and in certain practical conditions it is essentially impossible. This report discusses typical scenarios of laser beam propagation through atmospheric turbulence, provides an estimated efficiency of the beam delivery on a remote target, and the performance optimization required for adaptive optics applications with various type of beacon, including the beaconless scenarios. The report will review data of computer simulation for laser beam propagation in a relevant environment and the results of the laboratory tests.

9080-43, Session 8

Atmospheric turbulence effects on a monostatic and bistatic retroreflecting link

Rita Mahon, Mike S. Ferraro, Peter G. Goetz, Christopher I. Moore, James L. Murphy, William S. Rabinovich, U.S. Naval Research Lab. (United States)

No Abstract Available

9080-44, Session 8

Demonstrating capacity-approaching FSO communications

Thomas R. Halford, Michael P. Fitz, Cenk Kose, Jonathan Cromwell, Steven Gordon, TrellisWare Technologies, Inc. (United States)

Atmosphere turbulence causes time variation in the receive signal intensity on free space optical (FSO) communication links. Indeed, scintillation fades can stymie connectivity for milliseconds at a time. To approach the information-theoretic limits of communication in such time-varying channels, it necessary to either code across extremely long blocks of data – thereby inducing unacceptable delays – or to vary the code rate according to the instantaneous channel conditions.

In this paper, we describe the design, hardware implementation, and system performance of an FSO modem that employs low-density parity-check (LDPC) coding in an incremental redundancy (IR) hybrid automatic repeat request (H-ARQ) protocol. Our protocol effectively adapts the LDPC code rate to match the instantaneous channel capacity. For links with fixed throughput, this translates to the longest possible range in the presence of optical scintillation; for links with fixed range, this translates to the highest possible average throughput. By leveraging an LDPC that is amenable to low-complexity, high-throughput implementation in hardware, our modem is able to provide throughputs in excess of 850 Mbps on links with ranges greater than 15 kilometers.

Pending Government approval, we will also report on the results of recent system testing that was performed by researchers at the Naval Research Laboratory.

9080-45, Session 8

Implementation and performance of stochastic parallel gradient descent algorithm for atmospheric turbulence compensation

Greg A. Finney, Christopher M. Persons, Stephan Henning, IERUS Technologies, Inc. (United States); Jessie Hazen, Daniel Whitley, The Univ. of Alabama in Huntsville (United States)

IERUS Technologies, Inc. and the University of Alabama in Huntsville have partnered to perform characterization and development of algorithms and hardware for adaptive optics. To date the algorithm work has focused on implementation of the stochastic parallel gradient descent (SPGD) algorithm. SPGD is a metric based approach in which a scalar metric is optimized by taking random perturbative steps for many actuators simultaneously. This approach scales to systems with a larger number of actuators while maintaining bandwidth, while conventional methods are negatively impacted by the very large matrix multiplications that are required. The metric approach enables the use of higher speed sensors with fewer (or even a single) sensing element(s), enabling a higher control bandwidth. Furthermore, the SPGD algorithm is model-free, and thus is not strongly impacted by the presence of non-linearities which degrade the performance of conventional phase reconstruction methods. By implementing a high- and a low-speed deformable mirror (woofer-tweeter arrangement), large, low frequency and small, high frequency phase changes can be corrected. Results from laboratory experiments using phase plates as atmosphere surrogates will be presented, showing the impact of non-linear actuator response using the conventional and model-free approaches. The potential for high speed compensation using a woofer-tweeter configuration will be demonstrated.

9080-46, Session 8

Analysis of scintillation fluctuations of laser propagation through video data processing

Sara Belichki, Landon Splitter, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); Larry Andrews, Univ. of Central Florida (United States); Ronald Phillips, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

We seek to better understand laser propagation through the analysis of the fluctuations in scintillation data gathered from a 30 frame per second monochrome camera. Scintillation is the effect of atmospheric turbulence which is known to disrupt and alter the intensity and formation of a laser signal as it propagates through the atmosphere. To model and understand this phenomenon, we have inspected recorded video output of a laser upon a target screen to determine how much of an effect the atmospheric turbulence has disrupted the laser signal as it has been propagated upon a set distance. The techniques of data processing outlined in this paper moves us toward a more software-based approach to determining the effects of propagation and detection of a laser based on the visual fluctuations caused by the scintillation effect. With the aid of such visual models, this paper examines the idea of implementing mathematical models via software that is then validated by the gathered video data. Using the information yielded by the pixel values distributed within each individual frame, we are given the ability to extract data that is useful in understanding how atmospheric turbulence effects laser wave propagation. Examples outlined within this paper consist of plotting statistical results such as pixel correlation and mean laser signal fades, representing signal fluctuations of specified image pixels through audio, and modelling laser intensity from a retro-reflector with the issue of beam wander taken into account. Using these various

software-based techniques has rendered vast reconfigurability in how laser data may be processed to research the issue of atmospheric turbulence upon a laser system.

9080-47, Session 9

Diversity effects in modulating retroreflector links

William S. Rabinovich, Rita Mahon, Mike S. Ferraro, Peter G. Goetz, James L. Murphy, U.S. Naval Research Lab. (United States)

No Abstract Available

9080-48, Session 9

Experimental performance comparison of receiver architectures for airborne FSO systems

David W. Young, Juan C. Juarez, Johns Hopkins Univ. Applied Physics Lab. (United States); Brian Stadler, David F. Orth, Air Force Research Lab. (United States)

Over the past 5 years there have been multiple flight tests performed testing the performance of free space optical communications systems at ranges exceeding 100 km. There were significant differences in the systems architectures tested, the major difference being whether the systems utilized multi-mode or single-mode fiber to collect received light at the optical aperture focal point.

This paper describes the fundamental differences between the performance single-mode and multi-mode fiber coupled FSO systems from a receiver sensitivity standpoint. An analysis will be described that compares and contrasts the difference in fielded performance of two system architectures; the first being a tip/tilt based system coupled to a multi-mode optical fiber, the second being a curvature mode adaptive optics system coupled to a single mode fiber. The data used for this system analysis was taken during flight-testing performed during the AFRL FALCON and DARPA ORCA programs. The analysis will include the impact of the receiver architecture selected on link ranges, data rates, and overall link robustness.

9080-49, Session 9

Integration of a concentric five element InAIAs/InGaAs avalanche photodiode array in a stabilizing bi-static optical assembly

Mike S. Ferraro, Rita Mahon, William S. Rabinovich, James L. Murphy, U.S. Naval Research Lab. (United States); Wade T. Freeman, Smart Logic, Inc. (United States); Steve Frawley, Smart Logic, Inc. (United States) and U.S. Naval Research Lab. (United States); Peter G. Goetz, Harris R. Burris, Linda M. Thomas, U.S. Naval Research Lab. (United States); William R. Clark, William D. Waters, OptoGration Inc. (United States); Barry M. Mathieu, Barry Design, LLC (United States); Kenneth Vaccaro, Brian Krejca, OptoGration Inc. (United States)

In free space optical communication, photodetectors serve not only as communications receivers but as position sensitive detectors (PSD) for pointing, tracking, and stabilization. Typically, two separate detectors are utilized to perform these tasks but recent advances in the fabrication and development of large area, low noise avalanche photodiode (APD) arrays have enabled these devices to be used both as PSDs and as data communication receivers. This combined functionality allows for more flexibility and simplicity in optical assembly design without sacrificing the sensitivity and bandwidth performance of smaller, single element data receivers. This work presents a large area, five element concentric avalanche photodiode array rated for bandwidths beyond 1GHz with a measured carrier ionization ratio of approximately 0.2 at moderate APD gains. We discuss the integration of this array in a bi-static optical interrogator where it acts as a data receiver and provides position information for pointing and stabilization. In addition to front-end and digital electronics design, we also describe the optical assembly design and the development of a pointing and stabilization algorithm.

9080-50, Session 10

The integrated atmospheric characterization system (IACS)

David W. Roberts, Gary G. Gimmestad, John M. Stewart, Georgia Tech Research Institute (United States)

The Georgia Tech Research Institute (GTRI) is delivering a transportable multi-lidar instrument known as the Integrated Atmospheric Characterization System (IACS) in 2014. The system will be housed in two standard shipping containers that will be transported to remote sites on a low-boy trailer. IACS will comprise three lidars: a 355 nm imaging lidar for profiling refractive turbulence, a 355 nm Raman lidar for profiling water vapor, and an aerosol lidar operating at both 1.06 and 1.625 microns. All of the lidar transmit/receive optics will be co-aligned on a common mount, pointable at any elevation angle from horizontal to vertical. The entire system will be computer controlled to facilitate pointing and automatic data acquisition. The purpose of IACS is to characterize optical propagation paths during outdoor tests of electro-optical systems. The tests are anticipated to include ground-to-ground, air-to-ground, and ground-to-air scenarios, so the system must accommodate arbitrary slant paths through the atmosphere with maximum measurement ranges of 5-10 km. Elevation angle scans will be used to determine atmospheric extinction profiles at the infrared wavelengths, and data from the three wavelengths will be used to determine the aerosol Angstrom coefficient, enabling Interpolation of results to other wavelengths in the 355 nm to 1.6 micron region.

9080-51, Session 10

Non-intrusive supersonic boundary layer characterization using wavelength modulation spectroscopy

Jose O. Negrette-Fernandez, Air Force Institute of Technology (United States); Michael S. Brown, Air Force Research Lab. (United States); Michael R. Hawks, Air Force Institute of Technology (United States)

Experimental results on the use of wavelength modulation spectroscopy (WMS) to characterize the temperature, axial velocity, pressure, and density gradient of the boundary layer in a supersonic flow will be presented. Theoretical predictions will be compared to actual data from a rectangular flowpath scramjet research facility, measured with a tunable diode laser scanning 759 nm - 762 nm about the molecular Oxygen rQ13 and rR13 absorption lines. The presentation will include a general formulation of a digital (Matlab-based) lock-in amplifier used to process the WMS data. Finally, there will be a discussion on the potential leading indicators of upstream movement of the isolator shock train that are present in the data, which may be useful predictors of scramjet unstart conditions.

9080-52, Session 10

Control of a small robot using a hybrid optical modulating retro-reflector/RF link

James L. Murphy, Mike S. Ferraro, William S. Rabinovich, Peter G.

Goetz, Michele R. Suite, U.S. Naval Research Lab. (United States);
Stanley H. Uecke, NovaSol (United States)

Tele-operated robots used for Explosive Ordinance Disposal (EOD) are ordinarily controlled using a radio frequency (RF) link. Use of RF links on the battlefield presents several challenges including spectrum allocation and jamming effects (both by the enemy and friendly forces). Several solutions have been attempted including electrical or fiber optic umbilicals and spread spectrum radios with varying degrees of success. Modulating Retro-reflector Free Space Optical (MRR-FSO) communications links avoid these effects entirely but are limited to line of sight operation. We have developed a system consisting of an MRR-FSO link with a tracking optical terminal, a conventional RF link and a deployable pod to provide a relay node bridging the FSO link to the operator and the RF link to the robot. The MRR-FSO link provides the capability to operate the robot in the presence of jamming while the RF link allows short range non line of sight operation. The operator uses the MRR-FSO link to drive the robot to a position downrange outside the influence of the jammer or other interference. Once the robot is positioned downrange near the area of operation the pod is deployed. This allows the robot to maneuver freely including venturing beyond line of sight using the short range RF link to maintain communications between the vehicle and pod while the FSO link maintains connectivity between the pod and the operator.

9081-1, Session 1

Comparative analysis of holmium-doped laser materials

Steve Bowman, Joseph E. Friebele, Woohong R. Kim, U.S. Naval Research Lab. (United States); Christopher G. Brown, Sotera Defense Solutions, Inc. (United States)

Host intrinsic properties of rare earth laser materials play a crucial role in the operation of longer wavelength laser systems. This paper examines the properties of the 2.1μm transition in trivalent holmium. The holmium 2.1μm laser system has demonstrated an important role in defense and medical applications. The optical properties of resonant optical pumping of the 5I7 5I8 Ho3+ transition have been examined in a broad range of host materials. Spectral and projected laser parameters are reported in a-SiO2, Y3Al5O12, Lu2O3, YLiF4, ZBLAN, and KPb2Cl5. These hosts were selected to cover the full range of crystal fields and phonon energies. The magnitude of the Stark splitting is crucial in resonantly pumped quasi-three level lasers. Electron-phonon coupling plays a key role in this mid-ir wavelength laser. Background absorption from hydroxyl impurity can pose impediments to power scaling. Optimal 2μm laser performances for these diverse host materials are contrasted.

9081-2, Session 1

Processing and characterization of polycrystalline YAG core-clad fibers

Hyun Jun Kim, Air Force Research Lab. (United States) and UES, Inc. (United States); Geoff E. Fair, Santeri A. Potticary, Matthew O'Malley, Nicholas G. Usechak, Air Force Research Lab. (United States)

As a fiber-laser gain media, YAG has attracted considerable attention due to its large surface-to-volume ratio and its high thermal conductivity, which is superior to that of silica-glass fibers. As a consequence, techniques which enable the fabrication of poly- and single-crystalline YAG fibers have improved significantly in order to leverage the advantages YAG-based devices should offer. In this work we have endeavored to reduce the scattering loss of polycrystalline-YAG-core fibers by enhancing our processing techniques using feedback from mechanical testing and through the development of a technique to encase doped YAG-core fibers with undoped YAG claddings using robust ceramic processing techniques. As a result, we have recently fabricated fibers with both core and claddings made up of polycrystalline YAG and subsequently confirmed that they indeed guide light. In this presentation, the processes leading to the fabrication and characterization results obtained on these fibers will be discussed.

9081-3, Session 1

Crystal growth, spectroscopy, and laser performance of resonantly pumped eye-safe Er3+:LuVO4 laser

Nikolay E. Ter-Gabrielyan, Viktor Fromzel, U.S. Army Research Lab. (United States); Z. Yan, Shandong Univ. (China); X. Yan, Lasence Inc. (China); Huaijin Zhang, Jiyang Wang, Shandong Univ. (China); Mark Dubinskii, U.S. Army Research Lab. (United States)

High optical quality Er3+:LuVO4 single crystals have been developed by Czochralski growth process. Absorption and emission spectra for the 4I15/2 x 4I13/2 transitions relevant to eye-safe laser operation have been investigated. It was found that Er3+ ion in LuVO4 exhibits unusually high absorption cross section which is of major importance for compact laser designs. An efficient, resonantly-pumped Er3+:LuVO4 laser emitting at 1610 nm (pi-polarization) or 1597.5 nm (sigma-polarization) has been demonstrated. For CW pumping by a narrowband Er-fiber laser at 1532 nm the maximum output power of 5.9 W was achieved at 1610 nm with the slope efficiency of 54.4%. This is believed to be the first reported laser operation based on Er3+:LuVO4 single crystal.

9081-4, Session 1

Holmium-doped laser materials for eye-safe solid state laser application

Woohong R. Kim, Steve Bowman, Colin C. Baker, U.S. Naval Research Lab. (United States); Catalin Florea, Sotera Defense Solutions, Inc. (United States); Guillermo Villalobos, Brandon Shaw, U.S. Naval Research Lab. (United States); Bryan Sadowski, Sotera Defense Solutions, Inc. (United States); Michael Hunt, Univ. Research Foundation (United States); Ishwar D. Aggarwal, Sotera Defense Solutions, Inc. (United States); Jas S. Sanghera, U.S. Naval Research Lab. (United States)

Trivalent holmium has 14 laser channels from 0.55 to 3.9 μm. The laser emission of most interest is the transition 5I7?5I8 near 2 μm because of its potential for use in eye-safe systems and medical applications. Currently Ho3+doped single crystal yttrium aluminum garnet (YAG), is the most extensively studied and widely used material. However, YAG is not the best host material for high-power laser systems due to its relatively low thermal conductivity. Here we report our recent result on the spectroscopic and calorimetric study of non-radiative losses in various holmium doped laser host materials. [1-2] It is found that the Lu2O3 is an excellent host material for holmium. In this paper, we present our recent results in the development of Ho3+ doped sesquioxides for eye-safe solid state lasers. The synthesis of high purity nano-powder and the optical, spectral and morphological properties as well as the lasing performance from highly transparent ceramics are presented.

1. R. S. Quimby, N. J. Condon, S. P. O'Connor, and S. R. Bowman, "Excited state dynamics in Ho:KPb2Cl5," Optical Materials Vol. 34, Issue 9, pp. 1501-1622 (2012).

2. S.R. Bowman, Shawn O'Connor, Nicholas J. Condon, E. Joseph Friebele, Woohong Kim, B. Shaw, and R. S. Quimby, "Non-radiative decay of holmium-doped laser materials," Proceeding of SPIE Photonic West 8638-2, (2013).

9081-5, Session 1

Growth, spectroscopy, and laser performance of rare-earth doped vanadate family crystals *(Invited Paper)*

Jiyang Wang, Haohai Yu, Huaijin Zhang, Shandong Univ. (China)

Efficient all-solid state lasers have been developed since successful production of laser diodes in last two decades. The most popular laser crystals are Nd:YAG, Nd:YVO4 and Ti:Al2O3. Among these, Nd:YVO4 is widely used in mid- and low- power output all-solid lasers, including commercial. Since 1990's, a series of rare-earth vanadate crystals have been grown including Nd-, Yb-, Tm-, and Cr-doped and Cr,Nd- codoped orthovanadates, including ordered as well as disordered (mixed) orthovanadate single crystals. In this family of crystals, Nd:YVO4 and the lasers based on it, were the most developed. GdVO4, LuVO4 and mixed GdxLu(1-x)VO4 , GdxY(1-x)VO4 and YxLu(1-x)VO4 crystals with different dopants were also grown. It was found that Nd and Yb doped GdVO4 has the highest thermal conductivity which is most promising for high-power laser applications. Nd and Yb doped $LuVO_4$ was found to have the largest emission cross section and good thermal conductivity, which is promising for good laser performance in most compact laser architectures. The mixed vanadate crystals possess large inhomogeneous spectral broadening favorable for ultrashort-pulse laser applications.

This presentation will discuss the growth, spectroscopic and other basic properties of these crystals. CW and passively Q-switched laser operation of these crystals will be comprehensively described.

A series of orthovanadate crystals of different Erbium doped $Lu_xGd_{1-x}VO_4$ have also been successfully grown and their spectroscopic properties have been determined.

9081-6, Session 2

Calibrated measurements of Er and Yb co-doped glasses for laser properties

Simi A. George, Joseph S. Hayden, SCHOTT North America, Inc. (United States)

Erbium-doped bulk glasses are of high interest to many applications in the defense and medical fields. The Er^{3+} laser performance in materials, especially in glass, can be enhanced by co-doping with large amounts of Yb^{3+}, thus enabling laser diode pumping of Yb^{3+}near 980 nm. Here, absorption by the Yb $^2F_{5/2}$ state transfers energy to the $^4I_{11/2}$ state of Er^{3+}, giving rise to sensitized emission with significant reduction in the absorption length of the gain medium. Aside from Yb, Cr and Ce doping is also used in glasses in order to enhance laser performance. For the development of future eye-safe laser products, SCHOTT initiated an internal program focused on examining the complex interactions between Cr, Ce, Yb and Er.

A number of glasses were manufactured with varying levels of the aforementioned active dopants. During the course of this study, it became apparent that the measurement conditions for absorption and emission have a significant impact on the calculated laser properties. The main contributor to such dramatic changes in the measured data is the Yb^{3+} in these glasses. Yb is typically incorporated in large amounts (10's of wt%) in glass, where it is known to absorb its own light. Thus, for an accurate analysis of laser properties with the variations in active ion concentrations, it is necessary to standardize these measurements.

In this report, our efforts in calibrating spectrophotometric and fluorescence emission measurements are detailed for general consumption. Instrument related contributions to the collected data are tediously analyzed and isolated until stable measurement conditions for accurate results are identified. Sample thickness ffects on lifetime is determined by extrapolating to zero concentration lifetimes for both Er and Yb. A method for achieving wavelength calibration of the fluorescence unit to be better than 0.2nm is also detailed. Finally, a comparison of the calculated laser properties for the different glasses in the study is outlined with any observable correlations to active ion concentrations.

9081-7, Session 2

Nanoparticle doping for improved power scaling of resonantly-pumped, Yb-free Er-doped fiber lasers

Joseph E. Friebele, Charles G. Askins, U.S. Naval Research Lab. (United States); John R. Peele, Soltera Defense Systems (United States); Barbara M. Wright, Colin C. Baker, Woohong R. Kim, U.S. Naval Research Lab. (United States); Jun Zhang, Radha K. Pattnaik, Mark Dubinskii, U.S. Army Research Lab. (United States)

Erbium-doped fiber lasers (EDFLs) are attractive for directed energy weapons applications because they operate in a wavelength region that is both eye-safer and a window of high atmospheric transmission. Typical fiber structures for cladding-pumped high energy lasers are either solid glass large mode area (LMA) step index (SI) or photonic crystal fibers (PCFs). In both cases it is necessary to have a relatively high Er core absorption because of the areal dilution of the pump intensity in the large pump cladding. However, it is well-known that Er ions tend to cluster in silica glass, and Al, which is effective in increasing Er solubility and reducing clustering, is typically co-doped in the fiber core at a much higher concentration than Er. The common solution-doping technique for making EDFs provides no mechanism for controlling the atomic environment of the Er, and in spite of the presence of Al, clustering still occurs. Lifetime quenching and cross-relaxation upconversion typically increase with increasing Er concentration.

Nanoparticle (NP) doping is a new technique for making EDFs where the Er ions are surrounded by a cage of aluminum and oxygen ions, thereby substantially reducing ion-ion energy exchange and its deleterious effects on laser performance. Er-doped boehmite, hydrous aluminum oxide AlO(OH) NPs, are formed by mixing $ErCl_3$ and $Al(NO_3)_3$ in a high pH solution; the pH controls their size. After washing, the NPs are dispersed in a solvent and then doped in-situ into the silica soot core of the preform. Calcination of the boehmite by thermal treatment removes the OH and converts AlO(OH) to $-Al_2O_3$.

Whereas solution doping requires in the incorporation of significant amounts of Al in the fiber core for sufficient [Er], producing an unavoidable increase in the refractive index (RI), we have found that for comparable concentrations of Er, there is only a minimal RI increase with NP doping. This is a particularly important result for PCFs where the core delta n must be 0. Furthermore, the lifetime of the Er luminescence has been measured to be ~11.5 ms for a wide range of [Er] in the NP doped fibers vs. < 10.5 ms for solution doping, indicating an absence of Er clustering and quenching. A comparison of the performances of Er solution and NP doped fiber lasers will be presented.

9081-8, Session 2

Compositional tuning of glass for the suppression of nonlinear and parasitic fiber laser phenomena

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Fiber lasers are susceptible to a number of nonlinear and parasitic effects that can significantly inhibit performance. From a system perspective, requirements of a fiber laser may cover average or peak power, amplitude stability, and spectral content of the source. Nonlinear and parasitic phenomena, including Brillouin scattering, Raman scattering, mode stability, self-phase modulation, four-wave mixing in multi-wavelength lasers, etc. can each influence one or all of these performance characteristics. Conventionally, these system-limiting undesirables have been addressed with complex waveguide designs. However, each of these light-medium interactions can be described by material coefficients that lead to estimates of 'threshold' values where these phenomena become significant. For example, this may be the Brillouin gain coefficient for Brillouin scattering, the nonlinear refractive index, n_2, for self-phase modulation, or the thermo-optic coefficient, dn/dT, for mode stability. Furthermore, these coefficients tend to be strong functions of the material, and surprisingly wide ranges of values exist between known material systems. For example, both the Pockels' photoelastic constant, p_{12}, and thermo-optic coefficient may be either positive or negative for a material. It follows logically that mixtures of materials with coefficients of opposing signs would then give rise to compositions where these coefficients may be zero. Examples of such effect negation may include the barium aluminosilicate system for p_{12} and the phosphosilicate or titanosilicate system for dn/dT. Compositional tailoring of the optical fiber is therefore suggested as an alternative means to suppressing these parasitics and methods to do so will be discussed.

9081-9, Session 3

Smart filters: protect from laser threats

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Technologies, Ltd. (Israel)

With the development of more powerful lasers and their implementation in various devices used worldwide, more intention should be drawn to laser threats to optics as well as to the human eye. In some scenarios, laser radiation may seriously interrupt the signal, from transient saturation and can lead to permanent damage. The problem exists in imaging sensors comprising of CCDs and other matrix detectors, human eyes or other imaging and non-imaging sensors in the visible and the IR range. One option is to use a notch filter to remove a narrow band of wavelengths. However, versatility of available wavelength agile lasers makes this strategy useless. Smart protection is therefore needed, that is transparent for low laser intensities and limit or block the high laser intensities, and is effective over a wide band of wavelengths.

KiloLambda developed Optical Power Control (OPC) devices that reduce laser power threat to a safe level for various optical systems. We introduce into optical systems, susceptible to be interrupted or damaged from laser, novel passive solid-state threshold-triggered Wideband Protection Filter (WPF) that blocks the transmission only if the power exceeds a certain threshold. KiloLambda's Wideband Protection Filter (WPF) product is a wideband, angle of impingement independent, solid-state filter that protects sensors, cameras and the human eye from over power laser threats. We propose, based on our proven technologies, a novel technology for protection of any imaging system, sensors and the human eye against laser threats from the visible and up to the IR.

9081-10, Session 3

Characterization of a new nonlinear optical material for Army laser eye protection applications

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Broadband nonlinear optical (NLO) materials can be used to protect eyes from the threat of damage from lasers operating across the visible spectrum. Based on its efficacy in absorbing 532-nm, nanosecond laser pulses and its unusually broad excited-state absorption spectrum, researchers at the Army Research Laboratory (ARL) several years ago identified one such material, a novel NLO absorbing dye in a polar organic solvent, as a promising candidate for this application. In the interim, the material has undergone a number of dramatic improvements: The solubility of the dye has been increased almost 600-fold, and the solvent has been carefully optimized to enable the active chromophore molecule to provide maximum protection under battlefield operating conditions. Successful optical design and engineering require reliable modeling results for the laser protection performance of the dye/solvent system(s) employed, but these results are only as accurate as the inputs to the models: in particular, to the various photophysical parameters characterizing the optical nonlinearity. Until recently, values of the parameters characterizing the NLO properties of the improved dye/solvent system had not been measured experimentally, previous work having instead relied upon reported parameter values for the original system. Recent work at ARL has corrected this deficiency. In this paper, we describe a complete NLO characterization of the improved dye/solvent system, and we report values of all relevant photophysical parameters.

9081-11, Session 3

HVPE of bulk In1-xGaxAs for sensor protection

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Bulk ternary semiconductors with a compositionally-tunable band gap are needed for sensor protection in infrared optical systems. Melt growth of semiconductors from mixed binary melts is plagued by severe segregation that results in compositional nonuniformity, constitutional supercooling, and ultimately interface breakdown and polycrystallinity. Crystal growth from the vapor phase is free from such severe segregation effects, but traditional vapor growth techniques used for III-V semiconductors such as molecular beam epitaxy (MBE) and metal organic chemical vapor deposition (MOCVD) are characterized by extremely slow growth rates (~1 μm/hour) which are impractical for producing the very thick layers (1000-1500μm) required for producing bulk optical components. Low-pressure hydride vapor phase epitaxy (LP-HVPE) offers all of the advantages of vapor growth (no segregation effects, ultra high purity, superior process control, in-situ diagnostics, low native defect concentrations, etc.) but at growth rates over 100X higher than those typical of MBE or MOCVD: in fact the 100-200 μm/hour rates achieved by HVPE are approaching those used for bulk semiconductor growth from the melt. Here we report the use of LP-HVPE to produce In1-xGaxAs devices with compositions up to 20% Ga and thicknesses (after substrate removal) approaching 1 mm. Typical growth parameters are as follows: substrate temperature of 600-700°C; reactor pressure of 20 mbar; HCl flow rates of 8 and 32 sccm over Ga and In; AsH3 flow rate of 120 sccm. Growth results on InAs, GaAs, and InP substrates are reported.

9081-12, Session 3

Quantitative laser safety analysis for application of high-energy lasers in a field test

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There is a variety of national and international standards for laser safety analysis that use the implicit assumption that radiation can be held below certain Maximum Permissible Exposure (MPE) levels anywhere in the unmonitored surrounding, i.e. that a Nominal Hazard Zone (NHZ) is restricted to definable localities. Obviously, this is impracticable when high energy lasers are applied in outdoor environments. New approaches as presented in IEC TR 60825-14, the UK MOD JSP 390 Laser Safety and also briefly touched in STANAG 3606 are based on methods for risk assessment that provide assistance for the use of high energy lasers under acceptable risk.

In the study reported here, we conduct a quantitative risk analysis focused on an application of high energy laser radiation in outdoor field tests. Thus we identify hazards within a particular field test environment and estimate the risks associated to them using a probabilistic approach. The risks are assessed for being acceptable by probability of occurrence and severity. General risk management processes then demand that risks that exceed an acceptable level need to be reduced through appropriate risk reduction measure that either reduce the probability of occurrence or the consequences of an accident associated to that hazard. Thus, after having verified that all our recommended measures are implemented to a sufficient extend, field tests may be conducted.

Even if the environment and particular risks vary, our proceeding and the risks identified provide valuable advice for further risk analysis to allow for laser applications with acceptable risk in outdoor environments.

9081-13, Session 3

A laser-based FAIMS detector for detection of ultra-low concentrations of explosives

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Federation); Anton V. Tugaenko, Inkram (Russian Federation)

A method for detecting and analyzing of small concentrations of explosives in air based on the laser ionization and the field asymmetric ion mobility spectrometry (FAIMS) was developed. The method includes a highly efficient multipass optical scheme of the intracavity fourth-harmonic generation of pulsed GSGG : cr3+ : Nd3+ laser radiation (λ = 266 nm) and the FAIMS spectrometer disposed within the resonator. The ions formation and detection proceed inside the resonant cavity. The laser ion source based on the multi-passage of radiation at λ = 266 nm through the ionization region was elaborated. On the basis of the method the laser FAIMS analyzer has been created. The analyzer provides efficient detection of low concentrations of nitro-compounds in air and guarantees a detection limit of 5 10–15 g/cm3 for cyclotrimethylenetrinitramine (RDX) and 3 10–15 g/cm3 for trinitrotoluene (TNT).

A non-contact method for analyzing of explosives traces from surfaces was developed. The method is based on the laser desorption of analyzed molecules from the surveyed surfaces followed by the laser ionization of air sample combined with the FAIMS. The pulsed radiation of the fourth harmonic of a portable (2.6 kg) GSGG : Cr3+ :Nd3+ laser (λ = 266 nm) is used. The laser desorption FAIMS analyzer have been developed. The detection limit of the analyzer equals 40 pg for TNT. The results of detection of TNT, RDX and HMX (octogene) are presented. It is shown that laser desorption of nitro-compounds from metals is accompanied by their surface decomposition.

9081-14, Session 4

50μm-core Yb-doped leakage channel fiber with flattened mode

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There is great interest in power scaling in fiber lasers for use in a wide range of applications such as manufacturing, medical, scientific research and defense. Power scaling of fiber lasers is mainly limited by nonlinear effects. Large-mode-area fibers have been used to mitigate this limit, such as the leakage channel fiber (LCF). Typically, the mode intensity profile in these fibers exhibits Gaussian-like structure with higher intensity at the center of fiber core. As a result, the effective mode-area is much reduced compared to the physical fiber core area. Thus, a flat-top mode with a uniform intensity distribution is more suitable for larger effective mode-area without having to increase core size. These flat-top beams are also of benefit in marking and material processing applications.

In this work, we demonstrate the first flat-top mode generated in a 50μm-core Yb-doped LCF fiber. The mode flattening from Gaussian beam to a flat-top one is achieved by using a 30μm uniform Yb-doped area in the core center with a refractive index very slightly below that of the background silica glass by 2x10-4. The resulting flat-top mode has a significantly increased effective mode area of ~1880um2, which is ~50% larger than that of a conventional uniform core. The flat-top mode in this work is the largest even demonstrated, with ~6 times the effective mode area of the flat-top mode record demonstrated previously. A 6m-long fiber is also tested in a laser configuration with a measured pump-laser transfer efficiency of ~93% at 1026nm with respect to the absorbed pump power at 975nm.

9081-15, Session 4

Highly reliable and efficient 1.5um-fiber-MOPA-based, high-power laser transmitter for space communication

Doruk Engin, Frank Kimpel, Kent Puffenberger, Slava Litvinovitch, Xung Dang, He Cao, Bruce McIntosh, Mark Storm, Rich Utano, Shantanu Gupta, Fibertek, Inc. (United States)

Laser based optical communication links for space provides more than an order of magnitude higher data rates than corresponding RF communication links. In addition, this is achieved with much smaller size, weight and power (SWaP) burden to spacecraft payloads, thereby making spacecraft resources available for enhancing or extending science missions and the mission productivity. Key to the success of space laser communication links has been the maturity and high-reliability of pump laser, fiber-optic components, single-photon counting detector technology, and maturity of pointing, acquisition and tracking (PAT) requirements. This has led to the demonstration of 5.6 Gbps optical communication links using <1W average power, between two spacecrafts in low-Earth-orbit (LEO), thereby facilitating high-data rate transfers with very low bit-error-rates (BER). However, asteroid, lunar and planetary (i.e. deep-space) optical communication links operate over much larger distances compared to LEO/GEO links, and high optical powers (>4 Watts), narrow linewidth (<6.5GHz) and diffraction-limited beam quality are needed.

Fibertek has developed a space qualify-able, highly efficient, high power, fiber based 1.5um laser optical module (LOM). System achieves 6W average and >1kW peak power with 8nsec pulses and <6Ghz linewidth. Stimulated Brillion scattering is managed by use of LMA fiber in final stage and precise linewidth control while maintaining the required diffraction limited, and highly polarized (PER>20dB) output. Total gain of 48dB is achieved with two stages minimizing size and component count of the system. The LOM is optimized for athermal, conductive cooling and reliable operation with low SWaP (8”x10”x2.375”, 6.74 lbs). We have developed improvements in modulation scheme and component specs and expected LOM wall plug efficiency over 16.0%. Highly efficient operation is sustained for a wide range of pulse-position-modulation (16 to 128-ary PPM) formats with pulse widths varying from 8nsec to 0.5nsec. The LOM maintains the required high extinction ratio (>33dB) operation for all the pulse formats. Pressure stress analysis, random vibration analysis and thermal analysis of the designed LOM predicts compliance with most NASA General Environmental Verification Standard (GEVS) levels for vibration and thermal cycling in vacuum environment. Preliminary environmental test results for vibration and thermal cycling in a vacuum environment will be presented.

9081-16, Session 4

Thulium fiber laser and application development

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Within the past 10 years, Tm:fiber lasers have emerged as a flexible platform offering high average power as well as high peak power. Many of the benefits and limitations of Tm:fiber lasers are similar to those for Yb:fiber lasers, however the ~2 μm emission wavelength posses unique challenges in terms of laser development as well as several benefits for applications. In this presentation, we will review the progress of laser development in CW, nanosecond, picosecond, and femtosecond regimes. As a review of our efforts in the development of power amplifiers, we will compare large mode area (LMA) step-index and photonic crystal fiber (PCF) architectures. In our research, we have found Tm-doped step index LMA fibers to offer relatively high efficiency and average powers at the expense of fundamental mode quality. By comparison, Tm-doped PCFs provide the largest mode area and quasi diffraction-limited beam quality however they are approximately half as efficient as step-index fibers and have therefore been limited to ~50 W maximum average power.

We will also review the development of applications based upon Tm:fiber lasers. In terms of defense related applications, the most prominent use of Tm:fiber lasers is to pump nonlinear conversion to the mid-IR such as supercontinuum generation and optical parametric oscillators/amplifiers (OPO/A). We have recently demonstrated Tm:fiber pumped OPOs which generate ~28 kW peak power in the mid-IR. In addition, we will show that Tm:fiber lasers also offer interesting capabilities in the processing of semiconductors and polymers.

9081-17, Session 4

Resonant tandem pumping of Tm-doped fiber lasers and amplifiers

Daniel Creeden, Benjamin R. Johnson, Glen A. Rines, Scott D. Setzler, BAE Systems (United States)

We have demonstrated efficient lasing of a Tm-doped fiber when pumped with another Tm-doped fiber. We believe this is the first experimental demonstration of resonant tandem pumping for Tm-doped fibers. In these experiments, we use a 1908 nm Tm-doped fiber laser as a pump source for another Tm-doped fiber laser, operating at a slightly longer wavelength (~2000 nm). Pumping in the 1900 nm region allows for very high optical efficiencies, low heat generation, and significant power scaling potential due to the use of fiber laser pumping. The trade-off is that the ground-state pump absorption at 1908 nm is ~37 times lower than at 795nm. However, the absorption cross-section is still sufficiently high enough to achieve effective pump absorption without exceedingly long fiber lengths. This may also be advantageous for distributing the thermal load in higher power applications.

In a core-pumped oscillator configuration, we have generated 2.55 W of output power at 2005 nm with 75% optical efficiency and 90% slope efficiency, with respect to launched pump power. This pumping approach has been tested on five different fibers, each with different doping concentrations and/or geometries, with similar results. We have also demonstrated this pumping method in an amplifier configuration, resulting in 9.8W of extracted power, with a 91.6% slope efficiency and 79% optical efficiency. We present these results in detail and show a path toward high efficiency power scaling using this resonant tandem pumping approach.

9081-18, Session 4

Comparative study of resonant and non-resonant clad-pumping of fiber lasers based on Yb-free, Er-doped fibers

Jun Zhang, Radha K. Pattnaik, Viktor Fromzel, Mark Dubinskii, U.S. Army Research Lab. (United States)

We have recently demonstrated significant scaling potential of resonantly cladding-pumped Yb-free, Er3+-doped fiber lasers. With resonant pumping (4I15/2 - 4I13/2) at ~1530 nm, when heat deposition can be limited by merely very small quantum defect, significant power scaling can be achieved without elaborate thermal management of fibers. In turn, non-resonant pumping to the second excited state of Er3+ (4I15/2 - 4I11/2) has a great advantage of utilizing the most efficient and best developed commercially available InGaAs/AlGaAs ~980-nm fiber-coupled diode laser modules, so that greater overall laser efficiency can be achieved in this case. In fact, due to limited availability of advanced fiber-coupled InGaAsP/InP diode laser modules at ~1530 nm, this pumping can be more practical if application allows for more involved thermal management. The conventional approach to power scaling of Er3+-doped fiber lasers with ~980-nm pumping assumes Yb3+ co-doping to make up for insufficiently strong 4I15/2 - 4I11/2 absorption of Er3+ itself, limited by low Er3+ concentration in silica-based fibers. This co-doping helps in solving the absorption problem, but (i) introduces additional loss and heat deposition due to less than perfect Yb->Er energy transfer efficiency, and (ii) ultimately limits power scaling at eyesafe wavelengths by engaging parasitic Yb lasing at high pumping power levels. Presented here are the results of our comprehensive comparative study of resonant and non-resonant clad-pumping of fiber lasers based on Yb-free, Er-doped fibers, which can be of great interest for fiber laser development utilizing fibers with high 4I15/2 - 4I11/2 absorption of Er3+.

9081-19, Session 4

Diode clad-pumped, CW Raman fiber laser for a single-aperture power scaling *(Invited Paper)*

Mark Dubinskii, U.S. Army Research Lab. (United States); Benjamin G Ward, U.S. Air Force Academy (United States); Jay W. Dawson, Michael J. Messerly, Paul H. Pax, John E. Heebner, Derrek R. Drachenberg, Lawrence Livermore National Lab. (United States); Jun Zhang, Viktor Fromzel, Nikolay E. Ter-Gabrielyan, Radha K. Pattnaik, U.S. Army Research Lab. (United States)

We have demonstrated and assessed power scaling potential and efficiency of a new type of single-aperture fiber laser directly scalable to DEW-relevant power: a low quantum defect clad-pumped CW Raman fiber power oscillator. The Raman fiber laser was pumped by fiber-coupled laser diode modules at 1532 nm to produce an eye-safe output at the first Stokes wavelength of 1641 nm (a quantum defect of ~7%). The first successful demonstration of a diode-clad-pumped CW Raman laser is based on a specially designed and fabricated Photonic Bandgap (PBG) silica fiber. Parasitic higher-order Stokes amplification, the key challenge for this approach, is prevented by implementation of a PGB design with low loss at the 1st Stokes wavelength but high loss at 2nd Stokes. Presented are the theoretical PBG fiber design, fiber fabrication and passive testing details, along with the first experimental laser results.

Support of this work by the High Energy Laser Joint Technology Office (HEL-JTO) is gratefully acknowledged.

9081-36, Session Posters-Tuesday

Highly-efficient, high-energy pulse-burst Yb-doped fiber laser with transform limited linewidth

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A Yb-doped, 1um fiber laser, outputting high energy (>1mJ) pulse-burst with high peak powers (>10kW) and narrow linewidth (<300MHz), is an attractive pump source for tunable periodically poled (PPx) crystal based optical parametric amplifiers (OPA). Fiber laser pumped PPx based OPA's are well suited for sensing, imaging and communication applications. For example NASA Goddard Space Flight Center has developed a versatile nanosecond-pulsed MgO:PPLN based OPA for gas (CH4, CO2, H2O, CO) detection. The OPA has sufficient wavelength tuning range for gas detection and can simultaneously output at both near-infrared (1.5-1.6um) and mid-infrared (3-5um) wavelengths. The pulse burst format allows for >40 fold energy scaling of the necessary micro pulse energy (~30-60uJ) to ~2mJ while maintaining linewidth and peak power for individual micro pulses. Furthermore, fiber laser based pumps can generate more sophisticated pulse formats such as pulse position modulation (PPM) for communication applications.

Here a turn-key 1064nm PM Yb-doped fiber amplifier generating >1mJ pulse burst energy (consisting of >40x3nsec pulses separated by 30nsec) with transform limited linewidth (<500MHz) is presented. The ~20W laser, based

on COTS Yb doped LMA PM-fibers is optimized for high energy (0.5-2mJ) and high peak power (>10kW) operation at low duty cycles (~0.1%). The laser operates at >10x the saturation energy level of the final stage gain fiber and achieves a high level of pulse-to-pulse peak power uniformity within the pulse-burst. High wall plug efficiency (>20%) for the FPGA controlled system is achieved by temporal and spectral ASE suppression and by spreading the necessary pulse pre-shaping losses (~12dB) in three different amplitude modulation points in the amplifier chain. Sub nanosecond FPGA control allows for amplitude pre-shaping of individual micro pulses and is capable of generating PPM pulse formats with minimal pattern dependent pulse to pulse energy variation. The VBG locked power amplifier stage pumps can be pulsed (>50usec pulse width) allowing for efficient operation in lower macro pulse repetition rates (<5kHz).

9081-37, Session Posters-Tuesday

A three wavelength erbium-doped fiber laser source based on fiber Bragg grating reflectors

Siyanda Qhumayo, Univ. of Johannesburg (South Africa)

A three wavelengths erbium doped fiber laser source is developed. The configuration is a ring cavity comprised of an erbium doped fiber as a gain medium, an optical circulator, optical isolator for unidirectional operation and a WDM optical coupler for coupling the laser diode pump source and the optical feedback of the ring cavity laser source. The broadband spontaneous emission generated in the gain medium is coupled out of the ring cavity via port 1 through port 2 of the optical circulator. On this port, the partial reflecting Bragg gratings are connected and their function is to select the oscillation wavelengths and to serve as the output coupler. The Laser source has emission at 1540nm, 1547nnm and 1555nm.

9081-20, Session 5

Widely tunable infrared source for molecular fingerprint spectroscopy based on OP-GaAs difference-frequency generation with a synchronized programmable fiber laser

Mathieu Giguère, Alain Villeneuve, Joseph Salhany, Youngjae Kim, Alexandre Dupuis, Bryan Burgoyne, Genia Photonics Inc. (Canada); Douglas Bamford, Physical Sciences Inc. (United States)

Considered as the fingerprint region of the molecules, the Mid-Infrared (Mid-IR) consists of absorption lines related to molecular vibrations. The development of laser sources in this spectral region is then of great interest since many applications are related to it such as remote sensing, pollutant monitoring, laser-based infrared counter-measures and narcotic/explosive detection. Genia Photonics recently developed a Widely Tunable Infrared Source (WTIRS) based on Difference-Frequency Generation (DFG) of its commercially available Synchronized Fiber Laser. We present here our latest laser source development as well as the results of its integration as a key component inside an explosive detection system.

The laser system is based upon a Programmable Laser (PL) whose emitted wavelength can be tuned continuously and rapidly up to 80,000 times per second onto which we synchronize electronically a Master-Oscillator Power-Amplifier (MOPA). The two lasers are then mixed into a nonlinear crystal, in particular Orientation-Patterned Gallium-Arsenide (OP-GaAs), in order to generate DFG (6.25-10μm, 1000-1600cm-1). Since the number of nonlinear crystals available in this spectral region is restrained, the choice of OP-GaAs became obvious because of its high nonlinear coefficient as well as its capability to obtain engineered structure in order to optimize the phase-matching bandwidth. From this system, mW DFG level tunable over the full specified spectral range has been generated without any angular nor temperature tuning.

This source has then been proven highly efficient to detect explosive traces. Standoff detection of meter range has been tested and trace level RDX has been detected on different substrates.

9081-21, Session 5

Growth of bulk orientation-patterned gallium phosphide (OP-GaP) for mid-IR laser applications

Peter G. Schunemann, Alice Vera, Lee Mohnkern, Xiaoping S. Yang, BAE Systems (United States)

Orientation patterned gallium phosphide (OPGaP) is an exciting new engineered nonlinear optical crystal for efficiently shifting widely available 1-micron laser sources deep into the mid-infrared for applications ranging from IRCM to imaging lidar. OPGaP templates were grown by MBE in a dedicated Varian Gen II MOD system modified by the addition of a small auxiliary chamber equipped with a hi-temperature thermal silicon cell for growing the lattice-matched, non-polar Si inversion layer. The system was also equipped with a two-zone phosphorus cracker for improved control of the P flux compared to prior work based on a GaP solid source. After loading and baking (300°C) a 3-inch GaP vicinal (100) substrate (4° off cut toward) in the system, a 200-nm-thick buffer was grown at a rate of 200 nm /h under a P pressure of 1.6x10-6 torr (~ 10 times higher than reference 5) at a substrate temperature of 545°C, followed by growth of 5 nm of Si at a rate of 4 nm/h while ramping the substrate temperature from 350°C to 495°C. A 2.7-nm-thick AlGaP smoothing layer and then a 100-nm-thick inverted GaP layer were grown at 200 nm/hr at P pressures of 8.5 x 10-7 torr and 1.14 x 10-6 torr respectively. The GaP inverted layer was then photolithographically patterned with grating periods ranging from 14.5 to 95.9 microns, then etched by reactive ion etching in BCl3 at rates of ~ 2 nm/s (0.4 nm/s for Si) down to the surface of the original substrate. After removing the photoresist the wafer was cleaned with a brief wet etch and reloaded into the MBE chamber for 200 nm of regrowth under the same conditions as the initial GaP buffer layer. Atomic Force Microscopy revealed that the inverted layer growth was free of anti-phase domains, and that the patterned grating structure exhibited good vertical propagation. The resulting 3-inch MBE-grown OPGaP templates were loaded into a commercial low-pressure hydride vapor phase epitaxy (LP-HVPE) reactor and thick quasi-phasematched layers (>600 microns) were grown at temperatures between 720°C and 800°C, 20 mbar reactor pressure, and V/III ratios between 2 and 10. Excellent vertical domain propagation was achieved for grating periods as low as 14.5 microns and thicknesses up to 185 microns at growth rates of ~ 110 microns/hr. Bulk device crystals were cut, polished, and AR-coated for in-plane pumping by 1- and 2-micron solid state lasers. Preliminary frequency conversion results will be reported.

9081-22, Session 5

Cascaded mid-IR Er:Y2O3 ceramic laser

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We report the first diode-pumped, continuous wave (CW), dual-wavelength operation of an Er3+:Y2O3 ceramic laser taking advantage of the cascaded (4I11/2 -->4I13/2-->4I15/2) laser action at ~2.7 and 1.6 μm. The selection of laser host was based on the low-phonon nature of the Y2O3 host, which renders the 4I11/2-->4I13/2 transition to be highly radiative. A spectrally-narrowed fiber-coupled semiconductor laser module at ~980 nm was used to directly pump the Er3+ upper laser level 4I11/2. The cascaded operation results in an almost three-fold increase in the overall power and efficiency, with the added advantage of significantly decreasing heat deposition into the laser medium. Detailed analysis of the output power, lasing wavelength and slope efficiency for each individual laser transition is presented for the CW regime. Also presented is the temporal behavior of each laser line as a function of pump pulse duration in the quasi-CW regime along with the analysis of further laser power scaling at room and cryogenic temperatures.

9081-23, Session 5

Demonstration of a quick process to achieve buried heterostructure QCL leading to high power and wall plug efficiency

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High power, good beam quality, efficient thermal dissipation and high wall plug efficiency (WPE) are crucial in the specific application areas of quantum cascade lasers (QCLs). As these lasers have reached the commercialisation stage, it is imperative that the fabrication processes are also less time consuming and cost-effective. Together with the optimal basic design, buried heterostructure QCL with semi-insulating regrowth offers unique possibility to achieve an effective thermal dissipation and lateral single mode. We demonstrate here buried heterostructure QCLs with a single step regrowth of highly resistive (>1x108 ohm•cm) semi-insulating InP:Fe in less than 45 minutes in a hydride vapour phase epitaxy reactor for burying ridges etched down to 10-15 μm deep. This has to be compared with the normally used growth time of several hours, e.g., in a metal organic vapour phase epitaxy (MOVPE) reactor. In addition, our process is largely insensitive to ridge profile, mask overhang and does not lead to rabbit-ear growth near the ridge. The as-cleaved lasers emitting at ~4.6 μm were characterized. Very reproducible results were obtained on the 5 mm long lasers of ridge widths varying from 6-14 μm. Besides being spatially monomode, TM00 all the characterized lasers exhibited WPE of ~8-9% with an output power of 1.5 – 2.5 W at room temperature and under CW operation. The performance can be further improved by proper mounting and facet coating. Thus, we demonstrate a simple, flexible, quick, stable and single-step regrowth process with extremely good planarization for realizing buried QCLs leading to monomode, high power and high WPE.

9081-24, Session 5

High-performance mid-infrared GaSb laser diodes for defence and sensing applications

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Mid-infrared spectral region (2-4 μm) is gaining significant attention recently due to the presence of numerous enabling applications in the field of gas sensing, medical, environmental and defense applications. Major requirement for these applications is the availability of laser sources in this spectral window. Type-I GaSb-based laser diodes are ideal candidates for these applications being compact, electrically pumped, power efficient and able to operate at room temperature in continuous-wave. Moreover, due to the nature of type-I transition, these devices have a characteristic low operation voltage, resulting in low power consumption, and high-temperature of operation.

In this work, we present recent progress of mid-infrared GaSb type-I laser diode development for spectral range 1800 nm-3000 nm. CW Watt-level output power with wall-plug efficiency >20% from multimode single-emitter is demonstrated as well as > 200 mW single TE00 mode emission.

9081-25, Session 6

Holographic phasing of fiber lasers: simple, scalable, broadband locking

Geoff P. Andersen, Ken R. MacDonald, Paul Gelsinger-Austin, Hua, Inc. (United States)

We present a new method to lock an unlimited number of lasers using a simple, inexpensive hologram and photodiodes. Multiple fiber laser inputs are sent through a fiber shifters and then onto two holographic optical elements that split each beam in two and mix them in pairs. By taking the ratio of intensities measured from photodiodes an error signal is generated which can be used to control the phase shifters to ensure continuous phase locking of pairs of lasers.

We have constructed an autonomous system that locks 8 lasers and occupies a footprint no larger than a laptop. Locking is robust and can be configured to work with lasers of any power and wavelength. Our current system operates at bandwidths of up to 10kHz but has the potential of 100MHz or faster using a two-stage, woofer-tweeter approach.

9081-26, Session 6

Experimental demonstration of phase locking of a 21-subaperture fiber-collimator array over a 7-km atmospheric propagation path

Thomas Weyrauch, Univ. of Dayton (United States); Mikhail A. Vorontsov, Univ. of Dayton (United States) and Optonicus (United States); Vladimir M. Ovchninnikov, Guimin Wu, Optonicus (United States)

Coherent combining of beams generated in a multichannel fiber-optical master oscillator/power amplifier system and transmitted through a tiled array of fiber collimators is a promising technology for high-power laser beam projection systems. In directed energy applications coherent beam combining implies phasing of the outgoing beams at a remotely located target by controlling their piston phases at the fiber collimator sub-apertures. Thus, phase control needs to mitigate both random phase shifts, which are introduced by the fiber laser and amplifier system, and phase distortions from refractive index fluctuations caused by atmosphere turbulence. In this paper, we report on the results from target-in-the-loop coherent beam combining experiments of an array of 21 beams over a 7-km atmospheric propagation path. The light returning from the target – a retro-reflector considerably smaller than the diffraction-limited beam size, i.e., an unresolved target – was collected by an array of receiver apertures. The combined power of the return light was used as performance metric for adaptive control of the piston, tip and tilt wavefront phase at each fiber collimator sub-aperture using an iterative stochastic parallel gradient descent (SPGD) technique. At the target, a part of the light incident to the retro-reflector was coupled out with a beam splitter and collected by an optical power meter. The average power measured within the target aperture with phase control working was up to 18 times higher than the values measured without phase control. This gain in power corresponds to about 85% of the theoretical maximum.

9081-27, Session 6

32-channel coherent-beam combination via LOCSET phase locking

Benjamin Pulford, Angel Flores, Air Force Research Lab. (United States)

Coherent beam combination (CBC) is widely recognized throughout the Department of Defense (DoD) and its industrial partners as a necessary technology for high power fiber based laser systems. Though fiber

amplifiers typically exhibit desirable characteristics such as diffraction limited beam quality, and excellent thermal management properties, they tend to be limited in total optical output power; especially when developing narrow linewidth devices. In this case undesired nonlinear phenomena such as stimulated Brillouin scattering (SBS), brought on by optically induced acoustic resonances in the fiber material, greatly limit the total output power of a fiber amplifier. To sidestep this limitation CBC techniques have been developed and successfully demonstrated throughout the research community. In this paper we will describe the basic operation of the Locking of Optical Coherence via Single-detector Electronic-frequency Tagging (LOCSET) technique developed by the Air Force Research Laboratory (AFRL) and report on the most recent CBC demonstration of 32 low power beams with a combined RMS phase error of ?/71. This document will also include a discussion on the optical heterodyne technique utilized to quantify beam combination performance.

9081-28, Session 6

Transient stimulated Brillouin scattering in kilowatt class fiber lasers seeded with phase modulated light

Iyad Dajani, Angel Flores, Benjamin Pulford, Ann Lanari, Timothy Madden, Shadi A. Naderi, Air Force Research Lab. (United States); Brian Anderson, Univ. of Central Florida (United States)

No Abstract Available

9081-29, Session 7

High-efficiency narrow linewidth diode laser pump source at 780nm

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There is a growing interest in the development of high-power and narrow-linewidth diode laser pump sources at 780-nm for pumping narrow absorption lines of gain medium in diode-pumped lasers. Here we present development of a high-brightness, high-efficiency, narrow-linewidth, and wavelength-tunable 780-nm fiber-coupled diode laser. The diode laser module consists of multiple single-emitter diode lasers that are free-space coupled into the fiber, and is wavelength locked using wavelength-selective feedback provided by means of an external volume Bragg grating (VBG). The module delivers a maximum power of over 120 W and > 50% conversion efficiency as measured from the output of a 200 μm, 0.22 NA fiber. To the best of our knowledge, this is the highest conversion efficiency reported for a fiber-coupled 100-W linewidth-narrowed diode laser at 780 nm. The module is wavelength locked to <0.05 nm FWHM up to 60 W output power and <0.1 nm up to 100 W output power, and integrated wavelength tunability of > 0.6 nm is included to providing compatibility for closed-loop control of the center wavelength. An excellent 98% power percentage in the narrowband is measured for the spectrum, with broadband emission suppressed by more than 22 dB. Broadening of the emission bandwidth at >60 W of power is constrained by self-heating of the VBG due to optical absorption in the VBG glass.

9081-30, Session 7

Current pulse length investigation toward optimal pumping of a gain-switched asymmetric waveguide laser diode

Brigitte Lanz, Juha Kostamovaara, Univ. of Oulu (Finland)

Picosecond-range (~100ps), high energy (>1nJ) optical pulses generated by current pulse pumped semiconductor laser diodes are of interest in applications like high-precision laser radar [1], three-dimensional (3-D) time imaging, spectroscopy and lifetime studies. A well-established technique which allows the generation of short optical pulses is called gain-switching [2]. However, the optical pulse energy produced by commercial laser structures with this technique is moderate and relaxation oscillations are likely to build up. Diverse laser diode structures and structure modifications are described in literature [3-5] to achieve high optical energies and to suppress relaxation oscillations but are accompanied with implementation difficulties.

Our investigations are based on an edge-emitting semiconductor laser structure with strongly asymmetric waveguide and very large active layer thickness to optical confinement factor (da/?a) [6]. A laser with ~100 μm wide stripe and 1.5 mm long cavity meets mentioned picosecond-range and energy values under room temperature conditions when pumped with current pulses (~1.5 ns FWHM, 5 A, 1 kHz) generated by a silicon avalanche transistor based driver circuit [7].

Yet, at increased current pulse amplitudes in order to obtain increased optical pulse energies, the clean single optical pulse shape is distorted by relaxation oscillations which degrade the timing accuracy for example in use with a single-photon avalanche diode (SPAD) detector.

The gain-switched pulse energy and width depend besides device parameters on various input parameters such as drive current. The subject of our experimental investigations is the current pulse length which in turn affects the dynamic lasing threshold current pulse amplitude to find an optimal structure specific pumping current pulse aiming at optimized advanced gain-switched high peak-power picosecond pulses.

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9081-31, Session 7

Antireflective surface structures on windows for high-energy lasers

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The use of antireflective coatings on windows for high energy lasers

operating in the near infrared is limited due to optical damage that occurs under high power irradiation as well as delamination in the operational environment. New methods have recently been developed for fabrication of antireflective surface structures (ARSS) on optics to reduce reflection losses. The ARSS approach provides a more robust solution by using sub-wavelength surface structures that are fabricated directly into the actual surface of the optics, without the need for applying a coating with extraneous materials. We will report on results for ARSS fabricated on silica glass windows with applications for high-energy lasers. Recently we have reported very low reflectance (< 0.03%) near 1 μm for 1" diameter silica glass samples with random AR surface structures that were produced using reactive ion etching. These windows have shown remarkably high laser damage thresholds of up to 100 J/cm2 using a 1.06 μm laser with 10 nsec pulsewidth, which is 5x the threshold observed for a sample with conventional AR coating. We will report on the latest results for ARSS on large silica glass windows (up to 10 cm. diameter) and describe the progress towards fabricating ARSS on larger sizes up to 30 cm diameter.

9081-32, Session 7

Transverse mode selection in laser resonators using volume Bragg gratings

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Power scaling of high power laser resonators is limited due to several nonlinear effects. Scaling to larger mode areas can offset these effects at the cost of decreased beam quality. We present a new method of transverse mode selection which uses volume Bragg gratings (VBG) as an angular filter in large mode area laser resonators allowing for high beam quality.

VBGs recorded in photo-thermo refractive glass (PTR) have high stability, and high laser damage threshold, allowing for many applications to the design of high power lasers. In particular, gratings recorded in the transmitting geometry (TBG) have narrow angular selectivity. The narrow angular selectivity allows for increased losses for higher order modes, and allows for the TBG to be used as a spatial filter in the resonator.

An overview of transverse mode selection using VBGs is given, with theoretical models showing the effect of the angular selectivity of TBGs on the resonator modes. Applications of this ideology to the design of laser resonators, with cavity designs and experimental results presented for three types of multimode solid state lasers. A Nd:YVO4 with 1 cm cavity length and 2 mm diameter beam is presented with an M2 of <1.1. Applications to fiber lasers are discussed with results presented on a 13 core ribbon fiber with high far field beam qualitty. Finally, a multimode diode with diffraction limited far field divergence in the slow axis is presented.

9081-38, Session 7

Experimental verification of longitudinal spatial hole burning in high-power diode lasers

Ting Hao, Junyeob Song, Paul O. Leisher, Rose-Hulman Institute of Technology (United States)

For high-power diode lasers, asymmetric reflectivities of facets are employed in order to improve slope efficiency. In recent years, the cavity lengths of these laser diodes have been increased to better distribute heat in order to increase output power. However, these two methods result in an inhomogeneous longitudinal profile of photon density, which leads to a non-uniform gain profile and is typically referred to as longitudinal spatial hole burning (LSHB). LSHB is believed to one of the limiting factors in scaling the output power of diode lasers. In this work, the LSHB effect is confirmed experimentally. The longitudinal photon density distribution, carrier density distribution and gain distribution were calculated using a finite difference method to solve the spatially-varying rate equations in an 808 nm high-power diode laser. The experimental work was carried out by direct observation of spontaneous emission from a window patterned into the top contact of a 1.5 mm cavity length 808 nm diode laser. Because the spontaneous emission rate is proportional to the square of carrier density, the carrier density distribution could be measured for the device. The non-uniformity observed in this device agrees with the calculated carrier density profile, strongly supporting the existence of the LSHB effect in the device.

9081-33, Session 8

High-gain Yb:YAG amplifier for ultrashort pulse laser at high-average power

John Vetrovec, Drew A. Copeland, Amardeep S. Litt, Aqwest, LLC (United States); Detao Du, General Atomics Aeronautical Systems, Inc. (United States)

We report on a Yb:YAG laser amplifier for a kW-class average power ultrashort pulse applications. The laser uses two large aperture, disk-type gain elements fabricated from composite ceramic YAG material and a multi-passing architecture to obtain high gain in a chirped-pulse amplification system. The disks are edge-pumped [1, 2, 3], thus allowing for reduced doping of crystals with laser ions, which translates to lower lasing threshold and lower heat dissipation in Yb:YAG material. The latter makes it possible to amplify near diffraction-limited seed without significant thermo-optical distortions.

This work presents results of testing the laser amplifier with relay optics configured for energy extraction with up to 40 passes through the disks. This work was in part supported by the US Army ARDEC Contract Number W15QKN09C0156. Applications for the ultrashort pulse laser amplifier include laser material processing with no heat affected zone and laser acceleration of atomic particles.

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9081-34, Session 8

High-gain amplifier based on a hetero-composite Nd:YVO4/SiC gain assembly

George A. Newburgh, Mark Dubinskii, U.S. Army Research Lab. (United States)

We have demonstrated a diode-pumped solid state thin disk amplifier using the hetero-composite gain element, Nd:YVO4/SiC. The Thin Disk Prism amplifier, designed for optimal thermal management with good optical gain and low beam distortion characteristics, was shown to single-pass amplify a 50 W laser beam to a 140 W (gain greater than 3.5) over the 800 μm thick, 1% Nd:YVO4 layer. Multi-pass amplifier operation has also been evaluated and shown great potential for compact and high efficiency designs. A comparison of the beam quality before and after the amplifier, thermal analysis and modeling of amplifier performance will be presented.

9081-35, Session 8

Research on water-cooled lamp-pumped 8-radial slab solid state laser

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We reported in this paper on the successful demonstration of a water-cooled lamp-pumped 8-radial slab solid-state laser. The 8-radial slab, which consists of four crossing-slabs, was pumped by 8 Xe flash lamps simultaneously. One of main advantages is that the center of gain medium can be efficiently cooled, and the pump uniformity can also be improved. Thus, the effect of thermal lens and thermal stress of gain medium could be greatly reduced.

A diffuse reflecting pump chamber was used in the laser. Eight Xe flashlamps were arranged around the radial slab to produce a relatively homogeneous pumping profile. A plano-plano resonator was adopted in this laser system. Both sides of the radial slab were coated with-antireflection film. The output mirror, having a 10% transmission, was placed 0.4 m in front of the radial slab.

The experimental results showed that the output energy increased linearly with pump voltage. The threshold voltage for laser output is about 700V and the maximum pulse output energy 724mJ was obtained at the lamp voltage of 1000V.

The near-field pattern was observed 3 m from the output mirror by a CCD. The laser includes eight beams around with one beam in the centre. One compound laser beam was observed in the far field. Compared with numerical simulation we had done for 8 radial slabs solid-state laser, the incoherent, coherent and partially coherent laser beams were obtained.

This type of laser gives a new research direction for high power, high beam quality, and compact and scale power solid-state lasers. With a suitable design, yielding ten or hundred thousands of Watt laser with high beam quality is possible.

9082-1, Session 1

Extracting radar micro-Doppler signatures of helicopter rotating rotor blades using K-band radars

Rachel Chen, Baokun Liu, Ancortek Inc. (United States)

Radar micro-Doppler signature is a distinctive characteristic of target's identity through its micro motions. Helicopter identification has been an attractive topic to radar researches. To identify a helicopter type, besides its shape and size, the number of blades, the length of the blade, and the rotation rate of the rotor are important features for identifying the helicopter. These parameters can be estimated from the micro-Doppler signature of the helicopter.

In this paper, we introduce K-band at 24GHz CW/FMCW radars for studying returned signals from scaled helicopters. In the first measurement, we used RFbeam Microwave GmbH's K-MC1 sensor as the RF front-end and the ST200 Evaluation System as interface to host computer in CW mode. The second measurement was performed with our own high resolution K-band FMCW radar. We extracted radar micro-Doppler signatures from scaled helicopters and measured the angular rotation rate and the length of blades, the number of blades in the rotor, and other parameters of the helicopter rotor blades for distinguishing helicopters from other targets and identifying helicopter types.

9082-2, Session 2

Determining human target orientation and classifying human motion using bistatic radar micro-Doppler signals

Dustin P. Fairchild, Ram M. Narayanan, The Pennsylvania State Univ. (United States)

Micro-Doppler radar signals can be used to separate moving human targets from stationary clutter and also to identify and classify human movements. Traditional micro-Doppler radar systems which use a single sensor, monostatic system, suffer from the drawback that only the radial component of the micro-Doppler signal will be observed by the radar operator. This is because monostatic Doppler radars are capable of responding only to velocity components that are radially oriented towards or away from the radar antenna. If the target movement direction or oscillatory axis is perpendicular to the line-of-sight, then there is no Doppler signal available for processing. Thus, the sensitivity of human activity recognition is reduced if the movements are not directly towards or away with respect to the line-of-sight to the radar antenna. If multiple sensors are employed, additional information about the target can be inferred. In this paper, we propose the use of two bistatic micro-Doppler sensors to overcome this limitation. Of great interest in many applications is the orientation of an oscillating target with respect to the radar line-of-sight. While radar ranging is only capable of detecting the location of an object, an oscillating target's orientation can be determined by using multiple Doppler sensors. By using multiple sensors, the orientation of oscillating targets with respect to the radar line-of-sight can be inferred, thereby providing additional information to the radar operator. In addition, we conclude that multiple sensors can enhance the classification of micro-Doppler signatures. Our classification results clearly show that high accuracies are possible even if the target is not facing the radar line-of-sight and also for a bistatic radar configuration. If human motions could be performed in perfectly straight paths, the Doppler frequency for the scenario with a monostatic sensor and a target angle of 90 degrees should be zero. However, because a human target's motion will have some components in other directions, the radar is capable of detecting them.

9082-3, Session 3

IR polarimetric signatures

David B. Chenault, Joseph L. Pezzaniti, Polaris Sensor Technologies, Inc. (United States)

Infrared polarization relies on surface temperature, roughness, material properties, aspect angle to the sensor, sky down-welling and background radiance reflecting from the target. Often times, the polarization signature of a manmade target is different than the surrounding background. Furthermore, that difference is often present even when the thermal signature of the same target blends into the background. This paper will present maritime, airborne and ground data sets of polarization signatures of several objects that allow detection when other methods fall short.

9082-4, Session 3

Electric-field sensors for bullet detection systems

Stephen J. Vinci, David M. Hull, U.S. Army Research Lab. (United States)

Research and experimental trials have shown that electric-field sensors are effective at detecting charged projectiles and can likely complement traditional acoustic detection systems. The addition of electric-field sensors can result in a more robust and effective solution for bullet detection and tracking. For example, one challenge of acoustic sensors is in determining the bullet miss distance from the intended target. Electric-field sensors offer a particular strength in the detection of the point of closet approach to the sensor, and thus, would enhance the detection information available from the acoustic modality alone. However, electric field sensors are a newer technology that is relatively untested beyond basic experimental trials and has not been deployed in fielded systems.

The U.S. Army Research Laboratory (ARL) has conducted numerous live-fire experiments at Aberdeen Proving Grounds (APG) to collect data from electric-field sensors. Sensor types have included: electric potential gradiometer manufactured by Quasar Federal Systems, "D-dot" sensors designed and built by ARL and a varactor based E-field sensor prototype designed by University of North Carolina-Charlotte. Sensors were placed in strategic locations along the bullets' paths and their data were recorded. We analyzed the performance of each sensor type in regard to small-arms bullet detection capability. The most recent experiment in October 2013 allowed demonstration of second generation versions of the varactor and D-dot sensor types. Results of new real-time analysis hardware employing detection algorithms were also analyzed. The algorithms were used to process the raw data streams to determine when bullet detections occurred and to estimate bullet path.

Performance among the sensor types and algorithm effectiveness were compared to estimates from acoustics signatures and known ground truth. Results, techniques and configurations that might work best for a given sensor platform are discussed.

9082-6, Session 3

A collection and statistical analysis of skin reflectance signatures for inherent variability over the 250nm to 2500 nm spectral range

Catherine C. Cooksey, Benjamin K. Tsai, David W. Allen, National Institute of Standards and Technology (United States)

The spectral reflectance signature of human skin provides opportunities to advance observations ranging from medical treatment to security applications. In this study 100 volunteers participated in a skin reflectance measurement of the inside of the right forearm. The reflectance measurements were made over the 250 nm to 2500 nm spectral range. The

analysis included estimates of the variability attributed to the instrument, variability of the same subject, and between subjects. This allowed for determining measures of similarity and differences that indicate the inherent separability within the distribution. While this sample size may not fully represent a full diverse-population it does provide a provisional reference point for modeling and simulation.

9082-7, Session 3

Possibility of passive THz camera using for a temperature difference observing of objects placed inside the human body

Vyacheslav A. Trofimov, Vladislav V. Trofimov, Igor E. Kuchik, Lomonosov Moscow State Univ. (Russian Federation)

We demonstrate the possibility of using of a passive THz camera for a temperature difference observing in the human skin if this difference is caused by different temperatures inside the body. We discuss two physical experiments, in which a person drinks hot and cold water. After computer processing of images captured by passive THz camera TS4 we may see the pronounced temperature trace on skin of the human body. We illustrate this phenomenon by a series of images captured by passive THz camera in real time.

As we believe, these experiments allow to increase field of passive THz camera using for the detection of objects concealed in the human body because the difference in temperature between object and parts of human body will be reflected on the human skin. However, modern passive THz cameras have not enough resolution in temperature to see this difference. That is why, we use computer processing to enhancethe camera resolution for this application.

We discuss also other modern problems of the THz passive camera using.

9082-8, Session 3

NIST spectrophotometry support available for infrared signature measurements

Leonard M. Hanssen, Simon G. Kaplan, National Institute of Standards and Technology (United States); Jinan Zeng, Space Dynamics Lab. (United States); Sergey N. Mekhontsev, National Institute of Standards and Technology (United States)

Over the past two decades, the Infrared Technology Group at the National Institute of Standards and Technology (NIST) has developed comprehensive capabilities for high accuracy spectral characterization of the optical properties of solid materials and components in the infrared (IR) region from 1 um to 20 um and beyond. The primary goal of this effort has been to serve the needs of the diverse IR measurements community, including industry, academia, and government, by providing national scales for the optical properties, and means to establish traceability to them. A special focus in the development or our capabilities has been on DoD infrared signature requirements, with intermittent funding for specific developments provided by the Navy and Air Force.

For the IR community, NIST has provided calibration services, standard reference materials, short courses, as well as conducting a nation-wide intercomparison. The measured optical properties measurements are performed at a pair of facilities: the Fourier Transform Infrared Spectrophotometry (FTIS) laboratory, with measurements of transmittance, reflectance, absorptance and emittance; and the Laser Infrared Reflectometry (LIR) laboratory, with laser-based measurements of bi-directional distribution function (BRDF) and reflectance measurements of very low reflectance (very high emissivity) cavities. The optical properties are made with control and variability of the critical parameters including input angle, polarization, and temperature. A wide range of (primarily solid) sample types and sizes can be characterized and accommodated, including transparent, opaque, specular and diffuse. We will review support mechanisms for signature measurements, with recent examples and discuss the direction of capabilities expansion under development and planned

9082-9, Session 3

Investigation of atmospheric blasts by fast radiometry

Yossi Bushlin, Ronen Ben-Dov, Adam D. Devir, Alexander B. Lessin, Ilan Mendelewicz, Maria Shvebelman, IARD Sensing Solutions Ltd. (Israel)

Blasts and detonations release large amount of energy in short time duration. Some of this energy is released through radiation in the whole optical spectrum. Measurement of the blast signature may serve as a powerful approach for investigation of blast phenomena. A fast multispectral radiometer that operates in the proper chosen spectral bands provides extensive information on the physical processes that govern the blast. This information includes the time dependence of the temperature, area, composition of aerosols and gases in the blast flash, as well as minute changes in the blast expansion. Analysis of the blast signature provides indications on the order of the detonation, materials and masses of high-explosives and casing.

This paper presents the methodology and instrumentation of fast multispectral radiometry in application to the blast signature measurement and analysis in a near-ground explosion test (NET). In NET the radiation of two high-explosive (HE) materials (TNT and composition B - CB) with wide range of mass and casing materials was investigated. Analysis of the measured explosions demonstrates the power of fast radiometry methodology and reveals the governing characteristics of atmospheric blasts.

9082-10, Session 3

Passive signatures concealed objects recorded by multispectral and hyperspectral systems in visible, infrared, and terahertz range

Mariusz Kastek, Marcin Kowalski, Henryk Polakowski, Norbert Palka, Military Univ. of Technology (Poland); Philippe Lagueux, Vincent Farley, Marc-André Gagnon, Telops (Canada)

Detection of concealed dangerous objects is a very demanding problem of public safety. So far, the problem of detecting objects hidden under clothing was considered only in the case of airports but it is becoming more and more important for public places like metro stations, and government buildings. Multispectral imaging - detection systems operating in wide spectral ranges from visible, through infrared, up to terahertz will increase the ability to detect threats.

The measurement laboratory stand consists of multiple cameras: visible, measurement thermal camera, passive imaging Fourier transform spectroradiometer and a passive terahertz camera. During measurements, various test objects were used - different types of guns, knives and imitation of home-made explosives. These objects were placed on the human body covered with different types of clothes in order to test the camera ability of detection. The measurement setup allowed to measure signatures of hidden objects in different measurement conditions. Application of various data processing methods made it possible to identify these signatures and develop methods for image processing in order to detect objects hidden under some types of clothes. The results of measurements as well as the measurement methodology are presented in the article.

9082-11, Session 3

Effective criteria developing for the identification of substance using the reflected THz signal

Vyacheslav A. Trofimov, Lomonosov Moscow State Univ. (Russian Federation)

We propose and discuss various criteria for the detection and identification of dangerous substance using pulsed THz signal in a reflection mode. These criteria are integral criteria in time. We develop various approaches for enhancement of features of a detecting substance in reflected THz signal under investigation.

We take into account a humidity of air in a room and therefore, absorption of THz radiation by water vapor. We apply these criteria for the detection of explosive for various situations. Among them we consider the complicated shape of the PWM C4 explosive and a mixture of explosives.

Monday - Friday 5 –9 May 2014

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9083-1, Session 1

Two-dimensional atomic-layer research and engineering (2-DARE) beyond graphene *(Keynote Presentation)*

Anupama B. Kaul, National Science Foundation (United States)

Carbon is truly a remarkable material, for not only sustaining life on earth, but for the promising materials properties it encompasses that emerge from its diverse and rich physical structures. Carbon based nanomaterials, such as graphene and carbon nanotubes, have been proposed for a wide variety of applications including beyond Si-CMOS architectures, interconnects, field-emission displays, photo-voltaics and nano-electro-mechanical-systems (NEMS). In particular, although graphene has been shown to exhibit remarkable electronic, thermal, mechanical and optical properties, the absence of a band-gap poses concerns for its attractiveness in some applications, particularly in digital electronics where high ON/OFF ratios are desired. While a band-gap is induced in graphene through quantum confinement by creating graphene nanoribbons, the band gaps nonetheless are small (few hundred meV) and it is challenging to maintain pristine edge chirality due to defects that are induced during nanofabrication of the ribbons. Recently, layered 2D crystals of other materials similar to graphene have been realized which include insulating hexagonal-BN (band gap ~5.5 eV) and transition metal di-chalcogenides which display properties ranging from superconducting to semiconducting. The device applications of such systems show promising characteristics where MoS2 transistors have been formed on flexible and transparent substrates, and transistors derived from 2D monolayers of MoS2 show ON/OFF ratios many orders of magnitude larger than the best graphene transistors. In this talk, I will provide an overview of the Electronics, Photonics and Magnetic Devices (EPMD) program in the ECCS division where graphene, as well as other layered 2D nanomaterials, are playing an important role for enabling innovative device applications in electronics, photonics and sensing. I will also provide an overview of the NSF 2-DARE initiative under the Emerging Frontiers in Research and Innovation (EFRI) program.

9083-2, Session 1

Recent progress on two-dimensional materials for RF communications and sensing *(Invited Paper)*

Tomas Palacios, Massachusetts Institute of Technology (United States)

Although there is no doubt that electronics has changed our world, semiconductor devices and circuits are in a relatively small number of places around us. For example, there are typically no semiconductors in neither the walls nor the floors of our houses, our cloth, or even the paper cup that we get in the coffee shop. This is quickly going to change thanks to the emergence of two-dimensional materials such as graphene and molybdenum disulfide (MoS2). These semiconductors will enable truly ubiquitous electronics. This talk will describe some of the recent progress towards making this long term vision a reality.

MoS2 is a three atom thick semiconductor with a direct bandgap of 2.4 eV. With an electron mobility in the 20 to 200 cm2/Vs range, it has orders of magnitude better transport properties than other materials competing for a place in future large-area ubiquitous electronics. We will describe some of the first digital and analog devices and circuits fabricated with this amazing material.

At the same time than MoS2 is excellent for digital and analog electronics, the one atom thickness of graphene, combined with its very high carrier mobility, makes it ideal for all kind of chemical and biological sensors. For example, strain sensors, glucose sensors, and neurological transducers have all been demonstrated. The combination of these devices with the advanced MoS2 circuits described above will allow a new generation of electronics truly ubiquitous and with tremendous new opportunities.

9083-3, Session 1

Novel layered 2D semiconductors as the building blocks for nano-electronic/photonic systems *(Invited Paper)*

Haibing Peng, Guoxiong Su, Debtanu De, Viktor G. Hadjiev, Univ. of Houston (United States)

Layered two-dimensional (2D) semiconductors beyond graphene have been emerging as potential building blocks for the next-generation electronic/photonic applications. Representative metal chalcogenides, including the widely studied MoS2, possess similar layered crystal structures with weak interaction between adjacent layers, thus allowing the formation of stable thin-layer crystals with thickness down to a few or even single atomic layer. Other important chalcogenides, involving earth-abundant and environment-friendly materials desirable for sustainable applications, include SnS2 (band gap: 2.1 eV) and SnS (band gap: 1.1 eV). So far, commonly adopted for research purpose are mechanical and liquid exfoliation methods for creating thin layers of such 2D semiconductors. Most recently, chemical vapor deposition (CVD) was attracting significant attention as a practical method for producing thin films or crystal grains of MoS2. However, critical yet still absent is an effective experimental approach for controlling the positions of thin crystal grains of layered 2D semiconductors during the CVD process. Here we discuss our research efforts in exploring various layered materials as the building blocks for nano-electronic/photonic applications, and demonstrate the controlled CVD production of thin crystal arrays of representative layered semiconductors (including SnS2 and SnS) at designed locations on chip, promising large-scale optoelectronic applications. Our work opens a window for future practical applications of layered 2D semiconductors in integrated nano-electronic/photonic systems.

9083-4, Session 1

Graphene and beyond-graphene 2D crystals for next-generation green electronics *(Invited Paper)*

Kaustav Banerjee, Univ. of California, Santa Barbara (United States)

Graphene – composed of a single layer of carbon atoms arranged in a hexagonal pattern, is the basic material for the family of low-dimensional allotropes of carbon known as carbon nanomaterials. These graphene based nanomaterials have extraordinary physical properties that can be exploited for their exciting prospects for a variety of applications. This talk will highlight and discuss the unique prospects of graphene based nanomaterials for designing next generation low-power, low-loss and ultra energy-efficient active and passive devices targeted for designing next-generation “green electronics”.

The discovery of Graphene has also opened up a new era for a wide range of 2D nanomaterials including monolayer transition metal dichalcogenides (TMD) (such as MoS2 and WSe2) and their unprecedented electronic applications. This talk will also provide an overview of such beyond-graphene 2D materials and highlight some applications uniquely enabled by these 2D crystals in the nanoelectronics domain and discuss related challenges and opportunities.

9083-5, Session 1

2D materials: From catalysis to optoelectronics *(Invited Paper)*

Linyou Cao, North Carolina State Univ. (United States)

Two-dimensional (2D) transition metal chalcogenide (TMDC) materials with a monolayer or few-layer of atoms have been emerging as the cutting edge of physical science. Unlike graphene, which is a semimetal with no bandgap by nature or a trivial bandgap by engineering, the 2D TMDC materials have substantial bandgaps comparable to those of conventional group IV and III-V semiconductor materials. As a result, the 2D TMDC materials promise a tantalizing prospect of scaling semiconductor technology down to a truly atomic scale!

In this talk, I will first introduce a unique self-limiting chemical vapor deposition process that we have recently developed for the growth of large-area (centimeter-scale), high quality, and uniform monolayer and fewlayer MoS2 films. These films with well-defined physical features provide an ideal platform for us to study the fundamentals in catalysis and exciton dynamics. To illustrate this notion, I will show our recent results in the catalytic activities and exciton dynamics of MoS2 films.

9083-6, Session 1

High-field and thermal transport in 2D atomic devices *(Invited Paper)*

Eric Pop, Stanford Univ. (United States); Vincent Dorgan, Ashkan Behnam, Univ. of Illinois at Urbana-Champaign (United States); Christopher D. English, Zuanyi Li, Stanford Univ. (United States); Sharnali Islam, Univ. of Illinois at Urbana-Champaign (United States)

Two-dimensional (2D) materials like graphene and transition metal dichalcogenides (TMDs) are uniquely suited for nanoscale field-effect transistors (FET) due to sub-nm channel thickness and lack of dangling surface bonds. Thus, unlike three-dimensional (3D) materials such as Si, FETs based on 2D materials would be more resilient to short-channel effects and would suffer less mobility degradation from carrier-surface scattering. Nevertheless, most existing studies of 2D materials have focused on large devices and low-field transport. By contrast, highly scaled 2D-FETs will require very good understanding of electric transport at high fields and thermal transport as relevant for large scale device integration.

In this talk we will describe our recent progress in optimizing transport at 2D-3D material contacts, examining high-field transport, FET scaling and thermal measurements at sub-100 nm device dimensions. For instance, we have recently uncovered transport physics at TMD and 2D graphene contacts with metal electrodes, including the roles of metal deposition conditions during fabrication and that of thermoelectric (Peltier) effects during transistor operation [1,2]. We will also describe our understanding of high-field transport in MoS2 and graphene, including the importance of self-heating effects on various substrates such as SiO2, BN and HfO2 [3,4]. Finally, we will describe our thermal measurements in suspended graphene [5] and in graphene devices with dimensions comparable to the electron and phonon mean free paths (~100 nm) [6]; the former yield the intrinsic behavior of this material, while the latter show quasi-ballistic thermal transport near room temperature, as well as significant phonon-edge scattering in narrow devices. The results are of importance for both electronic and thermal applications of 2D materials.

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9083-7, Session 2

Where art and technology meet: Origami for three-dimensional adaptive devices *(Keynote Presentation)*

Richard Vaia, Michael F. Durstock, Timothy J. White, Loon-Seng Tan, James J. Joo, Gregory W. Reich, Air Force Research Lab. (United States)

Origami, from ori meaning “folding” and kami meaning “paper”, is the traditional Japanese art of paper folding with roots back to the 17th century Edo era. Examples from the classic fold of a paper crane to the exquisite pieces from conventional artists show engineers that simple planer shapes can be transformed into complex architectures with unique combinations of robustness and motion. Today origami-inspired technologies range from air bags and medical stints, to travel maps and space-deployable solar panel arrays. Combining these concepts with thin-film flexible devices, such as displays, sensors, RF-IDs, and antennas, would enable the design and manufacturing of never-before-realized three-dimensional components that adapt, communicate and process during deployment and end-use. Key to this vision is establishing the design framework that provides assessment of the trades between crease patterns, material properties and local strain fields around the flexible devices. We will discuss recent efforts to extend current technical origami design tools to encompass rigid and compliant concepts, to integrate material properties, to consider failure models of active printed devices, and to ultimately optimize crease patterns for folding-sequence and distribution of actuation across the degrees-of-freedom of the morphing structure. Employing these tools, we will highlight the recent development of a deployable photovoltaic array based on the Miura fold that delivers up to an order-of-magnitude more solar power than currently deployed, wallet size, portable power systems.

9083-8, Session 2

Coherent phonons in carbon-based nanostructures *(Invited Paper)*

Christopher J. Stanton, Univ. of Florida (United States)

We have developed a theory for the generation and detection of coherent phonons in carbon based nanotstructures such as single walled nanotubes (SWNTs), graphene, and graphene nanoribbons. Coherent phonons are generated via the deformation potential electron/hole-phonon interaction with ultrafast photo-excited carriers. They modulate the reflectance or absorption of an optical probe pules on a THz time scale and might be useful for optical modulators. In our theory the electronic states are treated in a third nearest neighbor extended tight binding formalism which gives a good description of the states over the entire Brillouin zone while the phonon states are treated using valence force field models. We compare our theory to a variety of experiments for the low frequency radial breathing mode (RBM) in SWNTs. The systems include: 1) micelle suspended single-walled nanotubes, and 2) highly aligned nanotube films. The analysis of such data provides a wealth of information on the dynamics and interplay of photons, phonons and electrons in carbon based nanostructures.

This work was done in collaboration with the J. Kono group at Rice University and the R. Saito group at Tohoku University.

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9083-9, Session 2

Double graphene-layer structures for adaptive devices *(Invited Paper)*

Vladimir Mitin, Univ. at Buffalo (United States); Victor Ryzhii, Taiichi Otsuji, Tohoku Univ. (Japan); Maxim Ryzhii, Univ. of Aizu (Japan); Michael S. Shur, Rensselaer Polytechnic Institute (United States)

Among different carbon materials (diamond, graphite, fullerene, carbon nanotubes) graphene and more complex graphene-based structure attracted a considerable attention. The gapless energy spectrum of graphene implies that graphene can absorb and emit photons with rather low energies corresponding to terahertz (THz) and infrared (IR) ranges of electromagnetic spectrum. In this presentation, the discussion is focused on double-graphene-layer (double-GL) structures. In such GL structures, GLs are separated by a barrier layer (Boron Nitride, Silicon Carbide, and so on). Applying voltage between GLs, one can realize the situation when one GL is filled with electrons while the other is filled with holes. The variation of the applied voltage leads to the variations of the Fermi energies and, hence, to the change of the structure interband and intraband absorption of electromagnetic radiation and the variation of the tunneling current. The plasma oscillations in double-GL structures exhibit interesting features [1]. This is mainly because each GL serves as the gate for another GL. The spectrum of the plasma oscillations in double-GL structures, which falls to the terahertz range (THz) of frequencies, can be effectively controlled by the bias voltage.

In this presentation, we consider the effects of the excitation of the plasma oscillations by incoming THz radiation and by optical radiation of two lasers with close frequencies. These effects can be used in resonant THz detectors and THz photomixers [3,4]. Special attention will be paid to terahertz laser that would operate at room temperatures. We present the models of such devices, demonstrate their characteristics, and evaluate the device ultimate performance.

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9083-10, Session 3

Terahertz devices and device modeling *(Invited Paper)*

Stephen M. Goodnick, Marco Saraniti, Arizona State Univ. (United States)

Research and development in the exploitation sub-millimeter waves (300 GHz to 10 THz) has undergone impressive growth during the last decade, due to the potential technological uses, and its unique location between the microwave (i.e. electronic) domain and the optical one. This 'THz gap' is being closed from both sides with long wavelength optical sources and the advent of electronic devices capable of operation at frequencies above 1 THz. In the present talk, we discuss some of the present THz technologies and their applications. We then discuss the physics and modeling of ultra-high frequency high electron mobility transistors (HEMTs) which have achieved THz frequencies in terms of operating frequency. In particular, we focus on the use of the Cellular Monte Carlo (CMC) method for full band simulation of semiconductor transport and device modeling. The electronic band structure and phonon spectra are used as direct inputs to the program for both cubic, hexagonal, and strained crystal structures using both empirical and ab initio methods. The full anisotropic electron-phonon interaction is calculated from the rigid-ion model using the electronic structure, the atomic pseudopotential, and the full phonon dispersion and eigenvectors for both acoustic and optical modes. A complete anisotropic model of polar-optical phonon scattering is included in the simulation, where both LO-like and TO-like mode phonons interact with electrons, as well as piezoelectric coupling. Various elastic processes are accounted for including ionized impurity, neutral defects, and dislocation scattering.

We have applied the CMC method to the study of high field transport in GaN and GaN/AlGaN heterostructures, where good agreement is obtained between the simulated results, and experimental pulse I-V measurements of transport. For device simulation, the CMC algorithm is coupled to an efficient 2D/3D multi-grid Poisson solver. Results are presented of the application of this algorithm to several technological problems of interest for THz device operation, including ultra-short channel AlGaN/GaN HEMTs, and pseudomorphic InGaAs HEMTs. In particular, we are able to relate the maximum operation frequency of such devices to the non-stationary transit time across the effective gate length of such devices, which is defined by the region of electrostatic control under the gate electrode.

Finally, for quantum confined systems, we have extended the full-band method to the calculation of confined states using k•p wavefunctions as well as atomistic tight binding calculations using a sp3d5s* atomic orbitals. We discuss this approach as applied to the modelling and simulation of InGaAs HEMTs and III-V nanowire transistors.

9083-11, Session 3

Investigation of MEMS bi-material sensors with metamaterial absorbers for THz imaging *(Invited Paper)*

Fabio Alves, Dragoslav Grbovic, Gamani Karunasiri, Naval Postgraduate School (United States)

There has been a continued interest in the terahertz (THz) imaging due to its penetrating and non-ionizing characteristics. Real-time imaging in this spectral range has been demonstrated using infrared microbolometer technology with external illumination by quantum cascade lasers (QCLs). However, to achieve high sensitivity, it is necessary to develop focal plane arrays using enhanced THz-absorbing materials. One attractive option to achieve real time THz imaging is MEMS bi-material sensors with embedded metamaterial absorbers, consisting of a periodic array of square metallic elements separated from a homogeneous metallic ground plane by a dielectric layer. We have demonstrated that the metamaterial films can be designed using standard MEMS materials such as silicon oxide (SiOx), silicon oxinitrate (SiOxNy) and aluminum (Al), to achieve nearly 100 % resonant absorption matched to the frequency of the illumination source, desired thermomechanical properties and access to external optical readout. The metamaterial structure absorbs the incident THz radiation and transfers the heat to bi-material microcantilevers that are connected to the substrate, which acts as a heat sink, via thermal insulation legs. The temperature rises in the bi-material legs allowing the overall structure to deform proportionally to the absorbed power. The amount of deformation can be probed by measuring the displacement of a laser beam reflected from the sensor's metallic ground plane. Several sensor configurations have been designed, fabricated and characterized to optimize responsivity, speed of operation and minimize structural residual stress. Measured figures of merit indicate that the THz MEMS sensors have a great potential for real-time imaging.

9083-12, Session 4

Growth of 2D heterostructures of graphene/bn *(Invited Paper)*

Michael G. Spencer, Cornell Univ. (United States)

Recent studies have shown that the performance of graphene can be significantly improved with the use of h-Boron Nitride on/under it due to

the atomically flat surface of h-BN, low interface charge trap density, and small lattice mismatch with graphene. All of these properties make h-BN an ideal dielectric or substrate material for graphene. Hetero-junctiona of graphene and h-BN (both vertical and lateral) can be utilized in devices such as tunneling transistor and atomically thin integrated circuits. In order to realize a 2D device technology it necessary to produce large area 2D films and hetero-junctions. The heterojunction growth problem separates into two elements; grow of graphene on BN and growth of BN on graphene. Several groups have reported previous demonstrations of the growth of BN on graphene. Growth of BN on graphene is facilitated due to the catalytic effect of graphene (cracking of the methane molecule), which is similar to that of metals while the catalytic action of BN is significantly smaller than that of graphene. A prerequisite for BN/graphene heterojunctions is large area growth of BN. We have pursued investigation of the growth of BN on both metal and insulating substrates and will present our current progress but to date film roughness (>5nm) is not low enough to allow CVD grown BN to be used as a substrate for graphene. In parallel with our BN growth effort we have studied the growth of graphene on single crystal BN without the use of a metal catalyst. BN flakes were exfoliated onto a sapphire substrate, which in turn was used in our growth reactor. Metal free direct growth of graphene on h-BN using a high temperature (~1550°C) chemical vapor deposition technique is was done under Ar environment. Growth temperature, methane partial pressure, hydrogen/methane flow ratio, and growth time were varied and optimized. Raman spectroscopy clearly showed the signature of graphene with G- (~1580cm-1) and 2D-mode (~2700cm-1). The smallest width of G- and 2D-peak was 30 and 55cm-1, respectively, and the Raman I2D/IG ratio varied between 0.7 and 1.8. Raman D-peak (~1350cm-1) shows a strong dependence on growth temperature with the smallest ID/IG value of 0.15 at 1550°C. In the case of long growth, nitrogen and boron doping were detected by x-ray photoelectron spectroscopy with a small Raman D'-peak. A continuous graphene film with the rms roughness (1?1 μm2 area) of 0.32nm was shown by atomic force microscopy. Early stage of growth revealed circular shaped nucleation islands, the density and heights of which are ~15/μm2 and 1-2 graphene monolayer, respectively. The hydrogen/methane flow ratio was found to be a critical parameter to obtain smooth 2D growth. We have found many similarities between the growth of graphene on BN and the growth of graphene on sapphire, which we have previously reported [ACS nano 7 2012]. Based on these studies we are able to expand our model of the graphene growth on BN and sapphire.

9083-13, Session 4

Recent advancements toward achieving graphene-based heterostructures *(Invited Paper)*

Virginia Wheeler, Nelson Y. Garces, Luke O. Nyakiti, Rachael L. Myers-Ward, Zachary R. Robinson, Neeraj Nepal, Sandra Hernandez, Scott Walton, D. Kurt Gaskill, Charles R. Eddy Jr., U.S. Naval Research Lab. (United States)

Graphene has attracted considerable attention as a material with excellent potential in a variety of applications including sensing, high frequency transistors, and energy storage. To realize such technologies, integration of scalable thin films onto graphene is required. Atomic layer deposition (ALD) is the preferred method to conformally coat planar as well as complex, high surface area nanostructures with abrupt interfaces and angstrom-scale control of thickness. However, the inert nature of graphene inhibits direct application of ALD films. We developed two novel dry chemical functionalization approaches using: (1) XeF2 and (2) a large-area plasma processing system (F, O, or N ions) which renders the graphene surface more amenable to precursor bonding without significant structural or electrical deterioration in the underlying graphene. Here, we will present the details of our functionalization approaches and ALD process, discuss its advantages and limitations with respect to other methods used to enhance graphene reactivity for ALD, and provide future directions for this field of study.

We have developed a novel dry chemical functionalization approach using XeF2 that results in thin, conformal, high-κ ALD oxide films, such as HfO2 (εHfO2=18.5) and Al2O3 (εAl2O3=8.9), on graphene, without degrading transport properties desired for low power, high frequency applications. By using this technique, a 10-25% improvement in graphene mobility and comparably small Dirac voltage shifts (HfO2=2V, Al2O3=0.1V) were observed, indicating the effectiveness of fluorine functionalization.

For some applications, it is more beneficial to use different functional groups to initiate ALD growth on graphene. Thin, conformal, pinhole-free Al2O3 films were obtained on graphene surfaces modified with F, O, and N moieties using LAPPS to show the versatility of this approach. Furthermore, a spatial distribution of functional groups can be achieved using physical masks during plasma processing, which may be useful for bottom-up device approaches.

Both functionalization techniques explored here are not limited to ALD oxide films and have been used to deposit 2-11 nm of uniform, conformal ALD AlN, GaN, or InN directly on EG, which opens the possibility of such heterostructures for more complex device applications.

9083-14, Session 4

Interface engineered dry-transfer process for high-performance graphene transistor on flexible substrates *(Invited Paper)*

Sang Y. Yang, Joong Gun Oh, Dae Yool Jung, Chan Hak Yu, Byung-Jin Cho, Sung-Yool Choi, KAIST (Korea, Republic of)

Recently, graphene has gained a lot of interest and been studied intensively due to its unique and outstanding electrical, mechanical and optical properties. For the production of graphene, chemical vapor deposition (CVD) has become the most popular method to obtain large area, high quality graphene. To apply CVD-grown graphene to electronic devices, graphene itself should be transferred to insulating substrate such as SiO2, and PMMA-assisted transfer of graphene in water environment (so called 'wet transfer process) has been widely used for transfer purpose. However, because wet etching of metal growth substrate should be involved in wet transfer process, ionic impurities from etchant and by-product of metal etching are easily trapped at the interface between transferred graphene and target substrate, resulting in the degradation of electrical properties and the reliability issues of fabricated devices. In addition, hydrophilic surface is generally preferred for effective transfer of graphene, limiting the choice of target substrates. High temperature (over 300oC) annealing process used for the effective removal of PMMA residues on graphene surface provides another limitation of this method in realizing the flexible, plastic-based graphene devices. Therefore, direct delamination of graphene from growth substrate and transfer to arbitrary substrates including flexible and stretchable ones are being pursued these days to overcome several drawbacks of wet transfer described above.

In this talk, I will discuss novel method for graphene transfer on various substrates with direct delamination of graphene. Simple treatment of graphene/metal substrate and application of carrier layer onto the treated substrate enable the direct delamination and transfer of continuous graphene film. This method has capabilities of the large area transfer and the deterministic multi-layer stacking of graphene. Graphene transistor with top gate structure fabricated on SiO2 using our transfer method shows narrower distribution of Dirac voltages and comparable device performances, compared to that from conventional PMMA-assisted wet transfer, indicating the advantage of our metal-etching-free, direct delamination process. High performance flexible graphene transistor on plastic substrate can be also realized by this method. In addition to the demonstration of flexible graphene transistor, the related issues for transfer and device fabrication on flexible substrate will be discussed.

9083-15, Session 4

Piezoresitive graphene NEMS sensors *(Invited Paper)*

Max C. Lemme, Univ. Siegen (Germany); Anderson D. Smith, Sam Vaziri, KTH Royal Institute of Technology (Sweden); Stefan Wagner, Univ. Siegen (Germany); Frank Niklaus, Mikael Östling, KTH Royal Institute of Technology (Sweden)

We will discuss graphene-based pressure sensors, which utilize both graphene's extraordinary mechanical properties as well as the fact that it is only one monolayer in thickness. This extraordinary thinness of graphene gives it an excellent sensitivity. The device design consists of a monolayer sheet of graphene, suspended over a cavity, with air at atmospheric pressure trapped inside the cavity. When the device is subjected to a vacuum pressure, the air under the cavity will press against the membrane applying a strain to it. Our sensor design shows high sensitivity when compared with conventional silicon based pressure sensors without the need of a strain gauge. Our devices also have the added advantage of aggressive scalability while maintaining a high degree of sensitivity. The graphene based sensors work due to the piezoresistive effect, which we have demonstrated both theoretically and experimentally. Our theoretical predictions using Tight Binding Molecular Dynamics (TBMD) models suggest piezoresistive influences due to changes in the band structure of the graphene and are verified by experimental data. The device in its present form can potentially be fabricated with CMOS-compatible processes steps to allow co-integrating More than Moore functionalities with silicon technology.

9083-16, Session 4

Graphene micro- and nanoplasmonics: physics and applications *(Invited Paper)*

Farhan Rana, Cornell Univ. (United States)

Graphene supports plasmons that have frequencies in the terahertz to IR range at moderate carrier densities. These plasmons can be confined in patterned graphene micro and nanostructures which act as plasmon resonators. The high mobility of carriers in graphene, and the extreme tunability of the frequencies of the confined plasmons offer unique opportunities for device applications in areas such as, hyperspectral terahertz/IR imaging, terahertz/IR coherent sources and modulators, and chemical and biological sensing. Plasmons in graphene are strongly coupled to the interband electronic transitions. Electrons in the conduction band can spontaneously emit a plasmon and relax into the valence band. Conversely, a plasmon can get absorbed by exiting an electron from the valence band into the conduction band. In graphene plasmon oscillators, confined plasmon modes in graphene microstructures are amplified through stimulated emission in population inverted graphene to achieve a laser-like oscillation. In hyperspectral plasmon detectors, radiation absorption occurs predominantly near the plasmon resonance which can be tuned over almost three octaves. In this talk, the basic physics of graphene plasmons will be discussed and several device applications will be presented.

9083-17, Session 4

Graphene-based active and passive component development on transparent substrates *(Invited Paper)*

James H. Schaffner, Kyung-Ah Son, Hyok J. Song, Jeong S. Moon, Andrey A. Kiselev, Hwa-Chang Seo, Baohua Yang, Danny Wong, HRL Labs., LLC (United States)

In order to collect radio waves, radio frequency (RF) antennas and circuits must intercept the radio frequency signals from which information can be demodulated and decoded. Glass, the most common portal between outside and inside in visible optics, is also transparent to a large portion of the electromagnetic spectrum useful for radio wave communications. Since glass is everywhere, it would make sense to use glass as the substrate upon which to mount the antennas and electronics, but only if these structures can remain visibly transparent.

In this paper, we present our development to date of glass RF circuits along two tracks: 1) transparent antennas and 2) graphene based active and passive circuit elements. Along the first track we have demonstrated antennas made from nanowire films capable of an optical transparency of 72% and sheet resistance of 4-5 Ohm/sq. Along the second track, we have in so far demonstrated graphene on glass field effect transistors with an fmax of 7 GHz, varactors with 1.4:1 tuning range, resistors with 3-70 kOhm, and capacitors from 13-860 pF. This is just the start; our plans are to increase the frequency and tuning ranges of the active and passive devices. Since graphene is inherently transparent at visible wavelengths, we ultimately would like to merge these two tracks to integrate active and passive RF circuitry with the antenna either directly on glass or as an applique put on glass.

9083-18, Session 5

Nanowires: Building blocks for nanocomputing to nanobioelectronics *(Keynote Presentation)*

Charles M. Lieber, Harvard Univ. (United States)

Nanowires: Building Blocks for Nanocomputing to Nano-Bioelectronics

Nanoscience offers the promise of revolutionary advances in many areas of science and technology, ranging from electronics and computing to biology and medicine, yet the realization of this promise depends critically on the rational synthesis of unique functional nanoscale structures and their organization into well-defined circuits and systems. Here we highlight the power of semiconductor nanowires as a platform material for exploring new science and technology. First, a brief review of the 'chemical' synthesis of complex modulated nanowires will be highlighted as a central material in nanoscience for enabling the bottom-up paradigm. Second, we describe novel deterministic assembly methods that involve one initial patterning step with all subsequent steps registered to this initial pattern, including the assembly and interconnection of individual nanowire elements into complex circuits. Third, we will exploit these advances together with a novel architecture, to address the concept of assembling a nanocomputer, first introduced by Feynman in 1959, with the realization of a programmable nanoprocessor of unprecedented complexity. Last, we will describe exciting complementary advances at the frontier between nanoelectronics and biology – "nano-bioelectronics" – including nanowire probes capable of intracellular recording and stimulation at scales heretofore not possible with existing passive electrical measurements, and an 'out-of-the-box' look at what the future might hold in terms of merging nanoelectronic circuits with cell networks in three-dimensions to 'synthesize' cyborg tissues and cyborg organisms. The prospects for blurring the distinction between nanoelectronic circuitry, computation and living systems in the future will be highlighted.

9083-19, Session 5

Group IV nanotube transistors for next-generation ubiquitous computing *(Invited Paper)*

Hossain M. Fahad, Aftab M. Hussain, Galo A. Torres Sevilla, King Abdullah Univ. of Science and Technology (Saudi Arabia); Sanjay K. Banerjee, The Univ. of Texas at Austin (United States); Muhammad M. Hussain, King Abdullah Univ. of Science and Technology (Saudi Arabia)

Evolution in transistor technology from leaky single gate planar devices to energy efficient multiple gate non-planar ultra-narrow (< 20 nm) fins has enhanced the scaling trend of doubling performance. However, this performance gain has happened at the expense of arraying multiple devices (fins) per operation bit, due to their ultra-narrow dimensions (width). Additionally arraying degrades device off-state leakage and increases short channel characteristics, resulting in reduced chip level energy-efficiency. Therefore, I will focus on our novel nanotube device (NTFET) topology based on conventional group IV (Si, SiGe) channel materials [1-7]. This device utilizes a core/shell dual gate strategy to capitalize on the volume-inversion properties of an ultra-thin (< 10 nm) group IV nanotube channel to minimize leakage and short channel effects while maximizing performance in an area-efficient manner. I will also show that the NTFET is capable of providing a higher output drive performance per unit chip area than an array of gate-all-around nanowires, while maintaining the leakage and short channel characteristics similar to that of a single gate-all-around nanowire, the latter being the most superior in terms of electrostatic gate control. We believe for big data management our device will provide maximum benefits from performance-energy efficiency-functionality perspective.

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9083-20, Session 5

Piezotronics and piezo-phototronics *(Keynote Presentation)*

Zhong Lin Wang, Georgia Institute of Technology (United States)

Piezoelectricity, a phenomenon known for centuries, is an effect that is about the production of electrical potential in a substance as the pressure on it changes. Wurtzite structures such as ZnO, GaN, InN and ZnS, due to the polarization of ions in a crystal that has non-central symmetry, a piezoelectric potential (piezopotential) is created in the crystal by applying a stress. The effect of piezopotential to the transport behavior of charge carriers is significant due to their multiple functionalities of piezoelectricity, semiconductor and photon excitation. By utilizing the advantages offered by these properties, a few new fields have been created. Electronics fabricated by using inner-crystal piezopotential as a "gate" voltage to tune/control the charge transport behavior is named piezotronics, with applications in strain/force/pressure triggered/controlled electronic devices, sensors and logic units. Piezo-phototronic effect is a result of three-way coupling among piezoelectricity, photonic excitation and semiconductor transport, which allows tuning and controlling of electro-optical processes by strain induced piezopotential. The objective of this talk is to introduce the fundamentals of piezotronics and piezo-phototronics and to give an updated progress about their applications in energy science (LED, solar) and sensors (photon detector and human-CMOS interfacing).

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9083-21, Session 5

En route toward high-performance electronics based on carbon nanotubes *(Invited Paper)*

Qing Cao, IBM Thomas J. Watson Research Ctr. (United States)

Si based complementary metal–oxide–semiconductor (CMOS) technology will most likely continue to scale and dominate electronics for the next ten years or so with Si nanowire field effect transistors (FETs) as final product. III/V based tunnel FET and nanotube transistors are most promising candidates for the incoming post-Si era while nanotube devices are more suitable for high-performance electronics according to simulations. However, it is still a daunting challenge to realize practical devices and systems based on nanotubes, mainly limited by material issues. Here we will review some most significant recent advances, with focus on assembling high purity semiconducting SWNTs into well aligned arrays and improving contacts between SWNT and metal electrodes. We demonstrate that 99% semiconducting nanotubes can be assembled into well aligned ordered arrays with controllable and uniform pitch separation. Contact properties, especially methods to improve the contact length scaling behavior of SWNTs, are also discussed as they are critical for the performance of ultra-scaled FETs. These results show great promise for nanotube based high-performance electronics. Further optimization of the nanotube electronic type and diameter separation techniques, reduction of interface traps for better device consistency, together with CMOS compatible circuit and system level implementation, represent some most important directions for future work, where major challenges come from the requirement of extreme engineering control rather than intrinsic limitations of the material or processes.

9083-22, Session 6

Adaptive Optics Center of Excellence for National Security *(Keynote Presentation)*

Brij N. Agrawal, Naval Postgraduate School (United States)

This paper provides an overview of the research focus at Adaptive Optics Center of Excellence for National Security (AOCoE). The Center was established in May 2011 at the Naval Postgraduate School (NPS) with the sponsorship of the Office of Naval Research, National Reconnaissance Office, and Air Force Research Laboratory. The objectives of the Center are to conduct research in adaptive optics and related technologies focused on national security applications, and establish and operate the Segmented Mirror Telescope (SMT) and High Energy Laser Beam Control Research Testbed (HBCRT) as national users facility.

SMT is a 3 meter diameter telescope with six segments. Each segment has actuators for surface control and fine and coarse actuators for segment alignment. Shack-Hartman wave front sensor is used for surface control, phase diversity sensor for segment alignment, and fast steering mirror for jitter control. Testing of the primary mirror has been performed to evaluate closed surface control techniques using face sheet actuators and a 4 D interferometer. Tuned mass dampers are added to reduce relative vibration of segments by 80%.

The main objective of research in HBCRT area is to reduce risk in the development and operation of DoD HEL beam control systems. The focus of basic research is to develop adaptive optics techniques to correct for laser beam aberration due to deep turbulence. A low power beam control testbed for laboratory tests is developed. A 10 kW capable HEL Beam Control Testbed is under development for field tests.

9083-23, Session 6

Advanced deformable mirrors for high-power lasers *(Invited Paper)*

Justin D. Mansell, Jesse Jameson, Brian G. Henderson, MZA

Associates Corp. (United States)

Efficient propagation of light through the atmosphere requires the compensation of phase distortions induced by the atmosphere, thermal lensing, thermal blooming, or aero-optics. We have developed a deformable mirror engineered to compensate these aberrations while reflecting high power radiation with minimal heating and thermally induced distortion. We present the results of a multi-year effort to address many of the challenges with the existing state of the art while reducing cost, complexity, and manufacturing time.

9083-24, Session 6

Exploration of self-phasing in coherently-combined fiber lasers *(Invited Paper)*

James R. Leger, Univ. of Minnesota, Twin Cities (United States)

Fiber lasers offer an attractive path to high radiance sources due to their high optical conversion efficiency, excellent mode purity, and their effective management of thermal loading. Single spatial mode sources are now capable of multi-kilowatts of cw power. However at increased power levels, nonlinear effects start to degrade fiber laser performance. It is therefore important to explore optical systems that can combine the power of multiple fibers coherently. In many such systems, the phase control of the fibers is performed in a conventional manner using a feedback system consisting of a sensor and an optical actuator. In this paper, we explore other more exotic forms of fiber laser phase control. In particular, we report on observations of the Kramers-Kronig phase shift in fibers, and show how this effect can be used to control fiber arrays. Experimental results are shown quantifying this effect and illustrating how it could be used as an effective automatic control mechanism in future coherent beam combining systems. In particular, we show that the Kramers-Kronig effect is able to correct for all phase errors in a robust and effective manner at a variety of output power levels.

9083-25, Session 6

Beam control in multiphoton microscopy using a MEMS spatial light modulator *(Invited Paper)*

Thomas G. Bifano, Hari P. Paudel, Boston Univ. (United States)

In nonlinear imaging applications such as two photon microscopy, a coherent illumination beam is used to generate a nonlinear excitation signal at a point of focus. Because the excitation signal scales supra linearly with local intensity, such nonlinear imaging can produce adequate signal from the focal region even if the illumination beam is strongly scattered by the medium. This approach breaks down when the ballistic light intensity falls below the level of the background scattered light. In this work, we extend the range of multi photon microcopy by coherently combining modes of the illumination light through direct feedback to a fast micro machined spatial light modulator with 1020 mirror segments. The result is a substantial increase in imaging depth in strongly scattering media. In this paper we describe the technique, the control algorithms used, and the results obtained in imaging through tissue phantoms and mouse skull samples.

9083-26, Session 6

Scintillation field measurements for horizontal path atmospheric turbulence, image stabilization, and beam control *(Invited Paper)*

Christopher C. Wilcox, U.S. Naval Research Lab. (United States); Freddie Santiago, Sandia National Labs. (United States); Ty Martinez, Sergio R. Restaino, U.S. Naval Research Lab. (United States); Brett E. Bagwell, Junji Urayama, Sandia National Labs. (United States)

The turbulent effects from the Earth's atmosphere degrade the performance of any optical system within it. There have been numerous studies in the effects of atmospheric turbulence on an imaging system that is pointed vertically and we are investigating atmospheric turbulence characterization and correction for horizontally pointed systems. In collaboration with Sandia National Laboratories in Albuquerque, NM, an outdoor test facility has been instituted with various data collecting capabilities. Scintillation measurements are being performed 24 hours a day on a data collecting campaign for atmospheric turbulence site characterization and modeling. Along with the scintillation data, weather data is being collected and correlation of this data is being investigated. With proper modeling, an adaptive optical system can be designed, built, and utilized to correct for the often-extreme image degradation that can result from the horizontal atmospheric turbulence. In this paper, we present the data collection capabilities and initial data analysis from the field site.

9083-117, Session 6

Adaptive optics correction of a laser beam propagating underwater *(Invited Paper)*

Sergio R. Restaino, Weilin Hou, Andrey Kanaev, Silvia C. Matt, Carlos Omar Font, U.S. Naval Research Lab. (United States)

The use of Adaptive Optics (AO) to correct for aberrations in a wavefront of propagating light has become customary for Astronomical applications and is now expanding to many other areas going from medical imaging to industrial applications. However, the propagation of light underwater has remained out of the main stream AO community for a variety of reasons, not least the shear difficulty of the situation. Our group has become a program that attempts to define under which circumstances such a correction could be envisioned. We take advantage of the NRL laboratory facility in Stennis, MO, where a large Plexiglas tank of water is equipped with heating and cooling plates that allow for a well measured thermal gradient that in turn generates different degrees of turbulence that can distort a propagating laser beam. In this paper we report on the preliminary findings of this ongoing program. The paper will describe the facility and the AO test-bed, the measurements made and some of the preliminary result.

9083-27, Session 7

Development and application of fiber optic sensors for power and energy systems *(Keynote Presentation)*

Susan M. Maley, U.S. Dept. of Energy (United States); Robie Lewis, National Energy Technology Lab. (United States)

The National Energy Technology Laboratory (NETL) under the Department of Energy (DOE) Office of Fossil Energy (FE) is leading efforts to develop highly efficient and environmentally benign power generation systems utilizing domestic fuel resources. Emerging advanced energy systems have extreme conditions of high temperature, high pressure, and corrosivity that require monitoring beyond what is currently available in today's marketplace. Sensing in these harsh environments provide key information that impacts process control, performance, and reliability of the power system. Instrumentation and sensing technologies designed for harsh conditions will be outlined with specific focus on fiber optic based sensor designs for harsh environments to measure temperature, pressure, and gas composition.

In addition to the harsh environment monitoring needs, large central power systems are complex requiring a high level of system integration. To manage complexity and support the targets of high efficiency and environmental performance, low cost distributed sensing is needed throughout a plant. Optically-based materials, technologies, and designs to support a low cost distributed sensor network will also be reviewed. Challenges associated with applying novel sensing concepts will be introduced along with the opportunities that process modeling and control introduce to support novel sensor systems.

9083-28, Session 7

Laser-absorption sensing of gas composition of products of coal gasification *(Invited Paper)*

Jay B. Jeffries, Ritobrata Sur, Kai Sun, Ronald K. Hanson, Stanford Univ. (United States)

A real-time, in-situ monitor of the composition (CO, CH4, H2O and CO2) of the synthesis gas products of coal gasification (called here syngas) has been demonstrated during field-measurement campaigns in a pilot-scale entrained flow gasifier at the University of Utah and in an engineering-scale, fluidized-bed Transport Gasifier at the National Carbon Capture Center (NCCC). Tunable diode laser absorption spectroscopy (TDLAS) sensors have a long history for real-time, non-intrusive, in-situ monitoring of combustion systems with sensitive species-specific detection capability. However, efficient gasifiers operate at elevated pressures (10-50atm) where absorption transitions are collision broadened and absorption transitions that are isolated at 1 atm become blended into complex features. In addition, syngas product streams can contain significant particulate, producing significant non-absorption scattering losses of the transmission of laser light. Thus, laser-absorption measurements are problematic in syngas flows Stanford has pioneered a new wavelength-modulation spectroscopy strategy with 2f-detection and 1f-normalization (WMS-2f/1f) that can provide sensitive absorption measurements of species with spectra blended by collision broadening even in the presence of large non-absorption laser transmission losses (e.g., particulate scattering, beam steering, etc.). The design of a laser-absorption sensor for the detection of CO, CH4, H2O and CO2 was optimized for the specific application of syngas monitoring at the output of large-scale gasifiers. Results and lessons learned from these field measurement campaigns will be presented.

9083-29, Session 7

Industrial Raman gas sensing for real-time system control *(Invited Paper)*

Michael P. Buric, Jessica C. Mullen, Steven D. Woodruff, Benjamin T. Chorpening, National Energy Technology Lab. (United States)

Gas composition has not been utilized extensively as a possible input to process-control systems running at any appreciable rate due to the slow response of most gas sensors. In general, there is a need to replace slower gas chromatographs or electrochemical sensors with fast, non-destructive methods with less stringent calibration and operational needs. Here, we demonstrate a Raman sensing system which is capable of reporting the concentrations of numerous species simultaneously with sub-percent accuracy and sampling times below one-second for process control applications in energy or chemical production. The sensor is based upon a hollow-core capillary waveguide with a small, micro-sized bore with reflective thin-film metal and dielectric linings. The effect of using such a waveguide in a Raman process is to integrate Raman photons along the length of the sample-filled waveguide, thus permitting the acquisition of very large Raman signals for low-density gases in a short time. The resultant integrated Raman signals can then be used for quick and accurate analysis of a gaseous mixture. The sensor is currently being tested for energy applications such as coal gasification, turbine control, well-head monitoring for exploration or production, and non-conventional gas utilization. In conjunction with an ongoing commercialization effort, the researchers have recently completed 2 field-prototype sensors suitable for hazardous area operation and testing. Here, we report pre-commercialization testing of those field prototypes for control applications in gasification or similar processes. Results will be discussed with respect to accuracy, calibration requirements, gas sampling techniques, and possible control strategies of industrial significance.

9083-30, Session 7

Optical fiber Fabry-Perot interferometry for harsh environment sensing *(Invited Paper)*

Anbo Wang, Virginia Polytechnic Institute and State Univ. (United States)

Fiber Fabry-Perot (FP) interferometry is one of the most important tools for harsh environment sensing because of its great flexibility of sensor material selection, superior long-term stability, and nature of remote passive operation. Virginia Tech's Center for Photonics Technology has been involved in the research of this field for many years. After a quick review of the typical methods for the construction of F-P sensors, emphasis will be placed on the whitelight interferometry which is perhaps the most robust sensor demodulation technique today. The recent discovery of an additional phase will be presented and its significance to the sensor demodulation will be discussed. Finally, author's opinions about the future trends of fiber FP interferometric sensing will be shared.

9083-31, Session 7

Effective design and fabrication of harsh environment gas sensors *(Invited Paper)*

Prabir K. Dutta, The Ohio State Univ. (United States)

Solid-state electrochemical devices composed of stabilized zirconia electrolytes (YSZ), e,g, oxygen sensor is used extensively for sensing in combustion environments. However, sensors for detecting other gases have not been as forthcoming. We will present our work in the area of total NOx sensors based on YSZ and catalysis research. In the presence of oxygen, the heterogeneous catalytic reactions occurring on the surface of metal-oxide electrodes and electrolytes compete with electrochemical reactions. We find that the heterogeneous catalytic activity of WO3, yttria-stabilized zirconia (YSZ), and Pt containing zeolite Y (PtY) have a significant influence on the performance of solid-state potentiometric gas sensors. Pt electrodes covered with PtY and WO3 are used as the reference and working electrodes because of the significant reactivity difference, with WO3 being largely inactive toward catalytic NOx equilibration. Using highly catalytic active PtY to filter incoming gas mixtures can effectively remove interferences from 2000ppm CO, 800ppm propane, 10ppm NH3, as well as minimize effects of 1-13% O2, CO2, and H2O. New ways of deposition of electrodes as well as increasing sensitivity to ppb levels will be presented. The improvement in sensitivity has led to new applications, particularly monitoring human breath for diagnosis of asthma and upper airway inflammation. We will present MEMS-based strategies for manufacture of miniaturized sensors.

9083-33, Session 7

Metal oxide gas sensors on nanoscale *(Invited Paper)*

Andrej Plecenik, Ali A. Haidry, Tomas Plecenik, Pavol Durina, Martin Truchly, Comenius Univ. in Bratislava (Slovakia); Martin Mosko, Institute of Electrical Engineering (Slovakia); Branislav Grancic, Maros Gregor, Tomas Roch, Leonid Satrapinskyy, Comenius Univ. in Bratislava (Slovakia); Antonia Moskova, Institute of Electrical Engineering (Slovakia); Marian Mikula, Peter Kus, Comenius Univ. in Bratislava (Slovakia)

In this work we present a solid-state hydrogen gas sensor based on titanium dioxide thin films with novel electrode geometry. The TiO2 films were

prepared by reactive magnetron sputtering in Ar + O2 atmosphere followed by ex-situ annealing in air at temperature of 600 oC for 1 hour. Platinum electrodes were prepared by dc magnetron sputtering and optical and electron lithography. The gas sensing measurements were done at closed chamber in air flow regime. Sensitivity to hydrogen gas has been tested for H2 concentrations up to 10 000 ppm at operating temperatures ranging from room temperature to 150 oC. It is shown that in electrode geometry used in our sensors, for all tested operating temperatures both sensitivity and speed of such sensors is gradually increasing when size of the electrodes decreases below 1 μm and particularly below 100 nm. Moreover, dependence of the sensitivity and speed of such sensors on the operating temperature decreases at the same time and disappears for electrode size below 100 nm.

9083-34, Session 7

Use of nanostructured oxides for selective gas sensing *(Invited Paper)*

Bilge Saruhan-Brings, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); Yakup Goenuellue, Univ. zu Köln (Germany)

In this work, the focus is given to the NO2 sensing with nanostructured as well as Cr-doped TiO2. Titania nanotubular layers (TiO2-NTs) are better known with their use in dye-synthesized solar cells. In the field of gas sensors, the best known application of TiO2-NT layers is given with H2 sensing. TiO2–NT structures are commonly synthesized from pure titanium by anodic oxidation method. As literature indicates, gas sensing with titania can be modified by doping to obtain p- or n-type semiconductor behaviour. As undoped titania is widely used for CO and H2-sensing, Al- and Cr-doped titania is reported to be effective for NO2-sensing. Nanostructuring of TiO2 yields faster and more stable response toward CO and NO2 with almost no drift in sensor signal. By means of wet-chemistry method, we introduced Cr3+ to TiO2 NT-layers and tested for NO2 sensing at temperatures up to 500°C in the presence of CO. The characteristics of Cr-doping are investigated by XRD, EDX-TEM methods. Cr-doping of nano-tubular TiO2 sensors increased the NO2-selectivity considerably, indicating that p-type semiconductor behaviour and Cr-incorporation into the titania lattice. Effect of doping and layer thickness on sensing is investigated by means of impedance spectroscopic measurements and equivalent circuit modeling in order to optimize the sensors for real-time measurements.

9083-35, Session 7

Novel sensors to enable closed-loop active clearance control in power generating gas turbine engines *(Invited Paper)*

Jonathan L. Geisheimer, Meggitt Sensing Systems (United States); Tom Holst, Meggitt Defense Systems, Inc. (United States)

Blade tip clearance is a key design parameter for gas turbine designers to optimize engine efficiency. Closed loop active clearance control of blade tip clearance to improve engine efficiency during operation has been investigated for a number of years, but technical challenges in providing an accurate and survivable sensor within the first stage turbine environment has slowed the adoption of a full closed loop system. This paper summarizes the current state of the art in blade tip clearance sensors and details more specifically the work of the authors in using microwave probes for this measurement including a summary or recent results in demonstrating closed loop clearance control. The paper will review the different methods and sensors used to measure tip clearance including mechanical, eddy current, capacitance, microwave, and optical techniques. The paper will also summarize in detail the operation of the author's microwave approach to measurements. In addition, the various factors that influence sensor accuracy and the strategy to obtain accurate measurements in-situ and within high temperature environments is discussed. Application specific needs also need to be considered, such as case asymmetry need to be considered in order for closed loop clearance control strategies to succeed. Finally, tip clearance results will be presented from the microwave sensor when used with a thermally-based active clearance control system.

9083-100, Session Posters-Tuesday

Digital level microfabrication for advanced optical structures

Drew J. Boudreau, Marc Christophersen, Michael K. Yetzbacher, U.S. Naval Research Lab. (United States)

Hyperspectral instruments with physical sizes comparable to that of a bare sensing array are now possible. Compact Fabry-Perot (FP) etalon arrays allow for different spectral sensitivities to be assigned to the different pixels of a sensing array. Such arrays for hyperspectral imaging are commercially available (Proc. of SPIE v.8266, no. 82660Q), but underutilized due to cost and performance tradeoffs. FP arrays were first made possible by binary or logarithmic fabrication, which reduces the number of lithography steps to log2(N) where N is the number of distinct levels of material required for the integrated optical element. However, significant yield loss results from the several lithography steps required in this process. We introduce a new binary etching technique that allows for the creation of an arbitrary number of distinct levels with a single greyscale lithography technique. Our technique has been used for the fabrication of distinct levels of 1 nm rms flatness with a controlled 10 nm resolution. This technique has been used to fabricate a staircase structure with greater than 120 distinct steps directly on a COTS optical imager. Details of the fabrication technique and characteristics of the optical element will be presented.

9083-102, Session Posters-Tuesday

Wavelength-selective visible-light detector based on integrated graphene transistor and surface plasmon coupler

Christian W. Smith, Douglas Maukonen, Robert E. Peale, Masahiro Ishigami, Univ. of Central Florida (United States); Justin W. Cleary, Air Force Research Lab. (United States)

Novel photodetectors based on graphene field effect transistors (FETs) that operate in the visible spectrum have been created. Graphene is produced by chemical vapor deposition on copper and transferred on appropriate device substrates. The produced graphene devices are gated by the strong AC electric field associated with surface plasmon polaritons (SPP). The transistors are built on thin PMMA/oxide dielectric applied to the thin metal layer on Kretschmann SPP prism couplers. Measurement of photoresponse is done using a p-polarized visible laser diode and a goniometer to sweep the angle of incidence. SPP excitation resonance is observed as a strong decrease in specularly-reflected optical power at the resonance angle. The graphene-based phototransistors exhibit up to 40% change in channel conductance that closely follows the plasmon resonance line shape as the incidence angle is changed. The resonance angle depends on wavelength giving a means of wavelength selective detection with potential applications to wavelength multiplexing and spectral sensing.

9083-103, Session Posters-Tuesday

Analysis of flapping mechanism for acoustically actuated microrobotics

Christopher B. House, Samara L. Firebaugh, Jenelle Piepmeier, John Burkhardt, U.S. Naval Academy (United States)

With the end goal of medical applications such as non-invasive surgery and targeted drug delivery, an acoustically driven resonant structure is proposed for microrobotic propulsion. At the proposed scale, the low Reynolds number environment propulsion requires non-reciprocal motion from the robotic structure; thus, a "flapper" with multiple, flexible joints, has been designed to produce excitation modes that involve the necessary flagella-like bending for non-reciprocal motion.

The key design aspect of the flapper structure involves a very thin joint that allows bending in one (vertical) direction, but not the opposing direction. This allows for the second mass and joint to bend in a manner similar to a whale or dolphin's "kick" at the bottom of their stroke, resulting in forward thrust for the entire structure.

The proposed flapping structure was initially modeled with a lumped parameters model of three masses and two springs (functioning as flexible joints). A 3-D model was developed and implemented in COMSOL, and analyzed to determine the structure's natural frequencies and mode shapes. The model can be modified in order to achieve desired eigenfrequencies and to allow for parametric studies.

The milliscale flapper has been fabricated out of acrylic using a laser cutter. Initial testing has led to confirmation that the proposed flapper design matches COMSOL predictions of natural frequencies. Further testing will be conducted within a fluidic environment in order to study the effect on the structure's natural frequencies as well as determine whether the effectiveness of the flapper's motion in producing forward thrust.

9083-104, Session Posters-Tuesday

Nanoimprint-assisted directed self-assembly of low-molecular weight block copolymers for advanced lithographic applications

Claudia Delgado Simão, Nikolaos Kehagias, Institut Català de Nanotecnologia (Spain); Michael A. Morris, Univ. College Cork (Ireland); Clivia Sotomayor Torres, Institut Català de Nanotecnologia (Spain)

Block-copolymers (BCP) are playing an important role in alternative lithographies to obtain sub-22 nm nanostructures on surfaces.[1] They are employed by a bottom-up approach based on BCPs microphase segregation on its constituent blocks originating cylinders or lamellas at the molecular scale. Top-down nanoimprint lithography (NIL)[2] and has been explored as a tool to direct the self-assembly (DSA) of the BCPs approach permits to subdivide the nanopatterns of the NIL stamp by 10 times, plus adding tunable molecular properties to the nanostructured surfaces. [3] To achieve BCP DSA using NIL methodologies, the stamp features have to be commensurable with the BCPs periodicity (L0). Generally, BCP DSA is guided by higher values of blocks interaction parameter (?n) which is known to give more ordered microphase domains, where ?n is inversely proportional to the temperature.[4] Here we use solvent vapors assisted nanoimprint lithography (SAIL) to combine bottom-up and NILup to 4" wafers .[3] Different molecular weights of BCPs PS-b-PEO and PS-PDMS were employed replicating the NIL stamp with high resolution. Moreover, microphase segregation was observed with features in the sub-20 nm size that exhibited different feature alignment as a function of the height of the mesas. Thus, our methodology permitted us to combine in one production step the NIL and the BCP DSA, using only milibar pressures and reducing to one third the nanofabrication time, when comparing BCPs with conventional annealing.

The research leading to these results has received funding from the European Union Seventh Framework Program ([FP7/2007-2013] project LAMAND under grant agreement n° [245565]) and by the Spanish Ministry of Economics and Competitiveness under contract no. MAT2012-31392 (Plan Nacional de I + D + I (2008-2011) The contents of this work are the sole responsibility of the authors.

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9083-105, Session Posters-Tuesday

Imaging quality comparison of two typical methods for imaging through turbid media

Xiaopeng Shao, Tengfei Wu, Changmei Gong, Xidian Univ. (China)

Due to the multiple scattering of light in turbid media such as biological tissues, the image of target becomes highly deteriorated and even disappears entirely. Only speckle patterns, which result from multiple scattering and interference in turbid media and contain disordered objects-information, can be acquired. Two typical methods to recover the image of target behind a turbid medium are described and simulated in this paper. The first approach is based on image correlation and wavefront shaping technique, in which the Pearson correlation coefficient is applied as a cost function for the optimization and genetic algorithm (GA) is employed to control a spatial light modulator to generate the optimal wavefront to maximize the cost function. For the second approach, the target images can be reconstructed from the speckle patterns with total variation minimization by augmented Lagrangian and alternating direction algorithms (TVAL3). Circular Gaussian distribution model and Rayleigh-Sommerfeld diffraction theory are exploited in our simulations to describe turbid media and light propagation between optical devices, respectively. Both GA and TVAL3 possess excellent anti-noise capability, while noise suppression always brings some negative impacts on image quality, thus the balance between noise suppression and imaging quality is also of great importance. Accordingly, we compare and analyze the imaging quality in different levels of noisy environments of the above two methods in detail so as to choose a suitable approach to obtain the optimal imaging quality in certain imaging conditions. This work will be beneficial to the fields of microscopic imaging and biomedical imaging in micro/nano scale.

9083-106, Session Posters-Tuesday

Sensing systems using chip-based spectrometers

Arthur Nitkowski, Kyle J. Preston, Nicolás Sherwood-Droz, Tornado Spectral Systems (United States); Jeffrey T. Meade, Yusuf Bismilla, Brandon DesRoches, Andrew T. Cenko, Elizabeth A. Munro, Jared Slaa, Tornado Spectral Systems (Canada); Bradford B. Behr, Tornado Spectral Systems (United States); Arsen R. Hajian, Tornado Spectral Systems (Canada)

Tornado Spectral Systems has developed a new chip-based spectrometer called OCTANE, the Optical Coherence Tomography Advanced Nanophotonic Engine, built using a planar lightwave circuit with integrated waveguides fabricated on a silicon wafer. While designed for spectral domain optical coherence tomography (SD-OCT) systems, the same miniaturized technology can be applied to many other spectroscopic applications.

The field of integrated optics enables the design of complex optical systems which are monolithically integrated on silicon chips. The form factors of these systems can be significantly smaller, more robust and less expensive than their equivalent free-space counterparts. Fabrication techniques and material systems developed for microelectronics have previously been adapted for integrated optics in the telecom industry, where millions of chip-based components are used to power the optical backbone of the internet. We have further adapted the photonic technology platform for spectroscopy applications, allowing unheard-of economies of scale for these types of optical devices. Instead of changing lenses and aligning systems, these devices are accurately designed programmatically and are easily customized for specific applications. Spectrometers using integrated optics have large advantages in systems where size, robustness and cost matter: field-deployable devices, UAVs, UUVs, satellites, handheld scanning and more.

We will discuss the performance characteristics of our chip-based spectrometers and the type of spectral sensing applications enabled by this technology.

9083-107, Session Posters-Tuesday

Modeling and simulation of multilayered thin films for terahertz detection

Fabio Alves, Naval Postgraduate School (United States); Michael F. Martin, U.S. Naval Academy (United States); Ricardo Augusto T. Santos, Instituto Tecnológico de Aeronáutica (Brazil); Dragoslav Grbovic, Naval Postgraduate School (United States)

In this article we demonstrate a method based on Transfer Matrix (TMM) that cam be used to analyze optical properties of multilayered thin films and planar metamaterials for terahertz (THz) detection. Producing and testing such films require host substrates that can be up to 4 orders of magnitude thicker than the THz sensitive films. Therefore, the ability to efficiently model, simulate and accurately predict the optical properties of multilayered structures with significant differences in thickness is crucial to designing sensors with maximized absorption. This method, which provides an analytical tool, less computationally intensive then finite element modeling, can be used for films composed of any number of layers with arbitrary thicknesses, aspect ratios and arbitrary angles of incidence. Homogeneous or patterned (metamaterials) films can be modeled enabling accurate analysis of positive and negative index materials indistinctly. Reflection, transmission and absorption of metallic/dielectric nanolaminates, metallic thin films and planar metamaterial films are analyzed and compared with experimental measurements and FE simulations. Results show good agreement for a wide range of structures, materials and frequencies and indicate that the method has a great potential for design and optimization of sophisticated multilayered structures for THz detection and beyond.

9083-108, Session Posters-Tuesday

Novel remote sensor systems: design, prototyping, and characterization

Stephen E. Gibbons, James E. Lamb III, Brewer Science, Inc. (United States); Ryan E. Giedd, Missouri State Univ. (United States)

We are developing a TRL4 radio-frequency (RF) sensing platform composed of a transmitter/receiver and a Bluetooth® device. The novelty of the transmitter design will ultimately enable deep penetration into the ground or metal structures to excite a sensing element. The receiver will pick up the signal from the sensing element and parse out stimulus data. The Bluetooth® device can integrate the sensor information into the existing sensor networks or other networks.

Sensing elements made of carbon nanotubes (CNTs) based on all-organic materials were printed on flexible poly(ethylene terephthalate) (PET)/Kapton® substrates. Resonance at very high frequency (VHF) was identified. The proposed novel sensing elements can take on different form factors, and the outputs of the sensing elements could be modulated by humidity, temperature, pressure, strain, or vibration stimulus. In this presentation, we will report results of our continued effort to develop a transmitter/receiver with a flexible and conformally mounted sensing element made of CNTs or copper materials on polyimide substrates over a broad range of frequencies. The overall performance of the sensing system with different sensing elements will be compared.

The novel remote sensing system can be integrated with passive and active sensing elements. It offers unique characteristics suitable for variety of sensing applications.

Bluetooth® is a registered trademark of Bluetooth SIG, Inc.

Kapton® is a registered trademark of DuPont.

9083-109, Session Posters-Tuesday

Bi-alkali photocathodes based on molecular beam epitaxy for next-generation sensors

Junqi Xie, Marcel Demarteau, Robert G. Wagner, Argonne National Lab. (United States); Xing Wang, Xi'an Institute of Optics and Precision Mechanics (China)

Next generation sensors such as photomultipliers call for high-performance photocathodes. Traditionally, bi-alkali photocathodes were grown through diffusion methods, making it hard to control the composition and crystallinity. Here, photocathode growth through molecular beam epitaxy (MBE) is introduced as a promising technique to obtain robust, highly efficient alkali-antimonide based photocathodes.

9083-110, Session Posters-Tuesday

Novel graphene FETs with field-controlling electrodes to improve RF performance

Chowdhury G. Al-Amin, Raju Sinha, Nezih Pala, Florida International Univ. (United States); Wonbong Choi, Univ. of North Texas (United States)

We propose a novel Graphene FET (GFET) with two capacitively coupled Field-controlling Electrodes (FCE) at the access regions. The FCEs could be independently biased to modulate sheet carrier concentration and thereby the resistance in the ungated regions. The reduction of source/drain access resistance results in increased fT compared to those of conventional GFETs with the same geometry.

The baseline conventional GFET in this study consists of Lg=3.0 μm and Lgs/Lgd=1.5 μm with SiO2 as substrate. We simulated the DC and RF characteristics of the baseline GFET using physics based numerical device simulation tool. The simulated DC and RF characteristics were in good agreement with the reported characteristics which validate our simulation method.

In the proposed device, two capacitively coupled FCEs are placed at the ungated access regions. We considered two devices for our analysis: (i) GFET-1; the long channel device with Lg=3.0 μm, Lacs=1.5 μm, μh=530 cm2/V.s and μe=336 cm2/V.s and (ii) GFET-2; the short channel device with Lg=0.5 μm, Lacs=1.5 μm, μe=4900 cm2/V.s and μh=3100 cm2/V.s.

The Id-Vds characteristics of both GFET-1 and GFET-2 in hole regime at different FCE bias depicted the decrement of Rs and Rd due to the decrement of access resistance, Racs. Analytical calculations also showed that for GFETs with a typical residual carrier (hole) concentration of 4.8 1012 cm-2, two 1.3 μm long FCEs each biased at -3 V can lower the Racs of GFET-1 with an initial value of 36.8 Ω down to 20 Ω.

We estimated RF improvement in both hole and electron regime of operation. For hole regime, the improvement of RF characteristics with FCE bias was estimated using both analytical technique and simulation. It was reported that low carrier mobility of Graphene did not show significant dependence on carrier concentration. Therefore, the hole mobility value for GFET-1 was kept constant at 530 cm2/V.s throughout the entire range of FCE bias, VFCE in both analytical and numerical analyses. On the other hand, Graphene hole mobility was considered to be significantly dependent on carrier concentration for the GFET-2, and its values at different VFCE were estimated using reported values for all analyses. The analytical technique resulted slightly higher cutoff frequency compared to that obtained from numerical simulations because of the limitations to take the additional parasitic capacitances introduced due to the FCE contacts into account.

Expected similar improvement of fT for GFETs in electron transport regime is also estimated using the simulation tool considering electron mobility to be concentration independent for GFET-1 and concentration dependent for GFET-2 as before.

In conclusion, Simulations supported by analytical calculations showed that, in hole regime of operation, FCE bias of -3V can increase the fT of both short channel and long channel GFET by 24% whereas for electron regime, it becomes 34% and 38% respectively. The proposed Graphene FETs with improved RF characteristics can be used for high frequency applications.

9083-111, Session Posters-Tuesday

Graphene shield-enhancement of photosensitive surfaces and devices

Nathan A. Moody, Los Alamos National Lab. (United States)

We investigate the utility of graphene to serve as a monolayer shield membrane to protect and ruggedize high quantum efficiency photocathodes and photodetectors in a number of applications requiring high reliability. As the strongest and thinnest material ever observed, graphene has become the rising star in nanoscience, exhibiting new physics and realistically accessible engineering properties that in many cases are orders of magnitude beyond that of conventional materials. Examples include: ultra-high electrical and thermal conductivity, optical transparency, impermeability to all molecular gases, high charge mobility, and ability to sustain extreme current densities. We seek new ways to overcome engineering challenges in the design of accelerator-based next-generation light sources, high power rf sources, x-ray tubes, and photon detectors. We use graphene as a protective membrane for photosensitive surfaces, predicting and evaluating the efficacy of the monolayer protection as well as the effect of this coating on the opto-electrical properties of a sample material. A targeted application area is extending lifetime of a photocathode and a photodetector. We report on preliminary results detailing the growth, integration, and characterization of graphene with photosensitive surfaces.

9083-112, Session Posters-Tuesday

An optically resonant position read-out system for microcantilever gas sensors

Gino Putrino, Adrian Keating, Mariusz Martyniuk, Lorenzo Faraone, John M. Dell, The Univ. of Western Australia (Australia)

This presentation describes a novel optical readout system for microcantilever gas sensors. A deflection noise density of 1 pm/sqrt(Hz) is demonstrated using low power infra-red lasers, giving rise to the ability to sense the thermally stimulated Brownian motion of microcantilevers at room temperature and pressure. This provides the ability to determine the resonant frequency of a cantilever without providing electrostatic actuation, which in turn gives rise to the ability to create remote sensing solutions using fiber-fed, passive MEMS sensors.

The optical readout system uses silicon photonics concepts, and is fabricated by patterning the epitaxial silicon layer of SOI wafer to form waveguides and diffraction gratings. The MEMS components are fabricated from SiN and Au using surface micromachining techniques.

By placing reflective microcantilevers above a diffraction grating which redirects light travelling through an input waveguide out-of-plane up towards the microcantilever, an optically resonant cavity is formed. The diffraction grating then couples the light back into an output waveguide. The intensity of the light in the output waveguide is modulated based on the position of the microcantilever, giving an extremely sensitive measure of that position.

9083-113, Session Posters-Tuesday

Methods for rapid chemical sensing with chemiresistive microsensing technology

Alexander Vergara, Kurt D. Benkstein, Stephen Semancik, National Institute of Standards and Technology (United States)

This study deals with pushing the limits of performance of microsensing technology developed at NIST/Gaithersburg. The microdevice sensors are based on microhotplate platforms and array structures populated with nanostructured materials (primarily oxides) to achieve sufficient sensitivity and selectivity. Temperature programming has been utilized to enhance selectivity, and lets the microsensor array be tuned for applications ranging from environmental monitoring to medical diagnosis. In this work, we focused our attention on specialized operational and analysis schemes to significantly reduce the time required for detection, recognition, and quantification of gas-phase chemical analytes. Specifically, we employed a microhotplate-based gas sensor with a thin, nanostructured chemo-sensing film of In_2O_3 exposed to a series of short pulses, 'bursts', of chemical analytes at different concentrations while its operating temperature was modulated by a rapidly-pulsed periodic temperature sequence with distinct systematically-varied semi-cycle period values, $\omega \in \{20, 30, \ldots 100 \text{ ms}\}$. Utilizing an aggregate of thermally-enhanced transient responses—a set of 'perturbed' optimally accelerated isotherms portraying an optimally accelerated version (relative to its un-perturbed isothermal response counterpart) of the response of the sensor during analyte exposure—generated with our approach above, we demonstrated the recognition and quantification of individual analytes at nearly real time. Our findings demonstrate high (up to 95% success rate) discrimination and quantification performances are still preserved while attaining a dramatically reduced response time of the sensing element from the typical 60 s (or more) down to only 3 s. Finally, we explored complex background environments and alternative solutions for further performance enhancement, including analogies between biological olfaction and our approach, both requiring multiple 'sniffs' from the same odor stimulus, as well as dynamic sensing conditioning with alternative operating parameters (UV illumination).

9083-114, Session Posters-Tuesday

Bi-material cantilever sensing technique for measurement of thermal properties of single nanostructures

Carlo Canetta, Arvind Narayanaswamy, Columbia Univ. (United States)

Bi-material microcantilevers, with their high sensitivity to thermal stimuli, are ideally suited sensors for investigating nanoscale heat transfer. We have designed and fabricated low thermal conductance bi-material microcantilevers by minimizing their width and thickness. The cantilevers have a pad area near the free end to accommodate a focused laser spot, keeping them suitable for detection with an optical deflection technique. Using such cantilevers, we have demonstrated heat flux resolution of less than 1 picowatt. A pair of such cantilevers is proposed as a configuration for measuring thermal conductance of a nanostructure suspended between the two. The configuration mimics that of the suspended microdevice measurement designed by Philip Kim and Li Shi, in which a nanostructure is suspended between two thermal reservoirs. In our cantilever technique, two lasers are focused, one on each cantilever. One laser is modulated to vary the temperature at the end of one cantilever, while the second laser senses variation in heat flow through the second cantilever due to thermal conduction along the nanowire. We have determined the resolution of such a device by measuring the background conductance between the two cantilevers in the absence of a nanostructure suspended between them. The background conductance is due to other pathways for heat transfer between the cantilevers besides nanostructure conductance. We have measured the background conductance to be as low as 0.05 nW/K. We show that this background conductance is primarily due to optical coupling – that is, the effect of light from the heating laser scattered from the edges of one cantilever and absorbed and sensed by the second cantilever. By measuring the background conductance for cantilevers varying the size of the pad on which the lasers are focused, we show that the background conductance decreases with increasing pad size. The larger pad size minimizes scattering from the cantilever edges. Further improvements in conductance resolution beyond 0.05 nW/K require reducing the background conductance due to optical coupling.

9083-115, Session Posters-Tuesday

Multiplexed optical operation of nanoelectromechanical systems (NEMS) arrays for sensing and signal processing applications

Ashwin Sampathkumar, Riverside Research Institute (United States)

NEMS are rapidly being developed for a variety of sensing applications as well as for exploring interesting regimes in fundamental physics. In most of these endeavors, operation of a NEMS device involves actuating the device harmonically around its fundamental resonance and detecting the subsequent motion, while the device interacts with its environment. Even though a single NEMS resonator is exceptionally sensitive, a typical application, be it sensing or signal processing, requires the detection of signals from many resonators distributed over the surface of a chip. Therefore, one of the key technological challenges in the field of NEMS is the development of multiplexed measurement techniques to simultaneously detect the motion of a large number of NEMS resonators. In this work, the important and difficult problem of interfacing with a large number of NEMS devices and facilitating the use of such arrays in, for example, sensing and signal processing applications is addressed. We report a versatile all-optical technique to excite and read-out a distributed NEMS array. The NEMS array is driven by a distributed, intensity modulated optical pump through the photothermal effect. The ensuing vibrational response of the array is multiplexed onto a single probe beam in the form of a high frequency phase modulation. The phase modulation is optically down converted to a low frequency intensity modulation using an adaptive full-field interferometer, and subsequently detected using a CCD array. Rapid and single step mechanical characterization of 44 nominally identical high-frequency resonators is demonstrated. The technique may enable sensitivity improvements over single NEMS resonators by averaging signals coming from a multitude of devices in the array. In addition, the diffraction limited spatial resolution may allow for position-dependent read-out of NEMS sensor chips for sensing multiple analytes or spatially inhomogeneous forces.

9083-116, Session Posters-Tuesday

A low-power CMOS flash ADC converter for temperature sensor

Md. Mamum, Md Mamun Bin Ibne Reaz, Mohammad T. Islam, Univ. Kebangsaan Malaysia (Malaysia)

This paper proposes a simple design of a flash analog-to-digital converter (ADC) in 0.18 μm CMOS technology. This ADC is expected to be used within a temperature sensor, which provides analog data output having a range of 360 mV to 560 mV. This system consisting of three main blocks is the threshold inverter quantization (TIQ)-comparator, encoder and parallel input serial output (PISO) register. The design goal is to get a flash ADC with low power dissipation, small size and compatible with the temperature sensors. The method is proposed to set each of the transistor channel length, for finding out the threshold voltage difference of the inverter each on the TIQ comparator. The design has an input range of 285 to 600 mV and 6-bit resolution output. The chip area of the designed ADC is 844.48 x 764.77 μm2 and the power dissipation is 0.162 μW with 1.6 V supply voltage.

9083-118, Session Posters-Tuesday

Spin-on organic polymer dopants for silicon

Bhooshan C. Popere, Megan L. Hoarfrost, Univ. of California, Berkeley (United States); Andrew T. Heitsch, Dow Corning Corp. (United States); Peter Trefonas III, Dow Electronic Materials (United States); Rachel A. Segalman, Univ. of California, Berkeley (United States)

Conventional doping of crystalline Si via ion implantation results in a stochastic distribution of doped regions in the x-y plane along with relatively poor control over penetration depth of dopant atoms. As the gate dimensions get to 10 nm, the related device parameters also need to be scaled down to maintain electrical activity. Thus, highly doped abrupt, ultra-shallow junctions are imperative for source-drain contacts to realize sub-10 nm transistors. Uniform ultra-shallow junctions can be achieved via monolayer doping, wherein thermal diffusion of a self-limiting monolayer of dopant atom-containing organic on Si surface yields sub-5 nm junctions. We have extended the use of organic dopant molecules in the monolayer doping technique to introduce a new class of spin-on polymer dopants. In effect, these new spin-on dopants offer a hybrid between the monolayer doping technique and traditional inorganic spin-on dopants. We have been able to uniformly introduce p- and n-type dopants with doping efficiencies comparable to the monolayer doping technique. Control over junction depth can be easily achieved via optimizing annealing temperature and time.

9083-36, Session 8

Novel solar cells using II-VI semiconductors *(Keynote Presentation)*

Sivalingam Sivananthan, James W. Garland, Christoph H. Grein, Robert F. Klie, Univ. of Illinois at Chicago (United States); Ramesh G. Dhere, Episolar Inc. (United States)

Different semiconductors have been investigated for use in polycrystalline thin-film solar cells. However, only CdTe/CdS cells have been successful enough to justify large-scale industrial production. First Solar (FS) began production in 2003-2004, reduced the production cost below $0.7/Wp and rapidly became the largest PV manufacturer. Cd emission is not an issue because Cd emission from the manufacture, use and recycling of CdTe/CdS compares with that from Si and is far less than that from other sources of electric power. However, to achieve grid parity, and remain economically competitive with Si modules, the price of which has dropped sharply, CdTe/CdS module performance must be improved to remain competitive. In particular, the open-circuit voltage, which is far below the theoretical limit for CdTe, must be substantially improved. UIC and Episolar are pursuing that goal in three novel ways: (1) using MBE to investigate the fundamental effects on device performance of controllably introducing grain boundaries and impurities found in poly-CdTe/CdS into single-crystal CdTe, (2) using CSS to perform substrate growth, rather than superstrate growth, to improve poly-CdTe material properties and (3) investigating polycrystalline CdS/CdTe/CdZnTe two-junction modules, which cannot be fabricated successfully using superstrate growth. In parallel, we are investigating ways to eliminate the fundamental causes of the previous poor performance of single-crystal CdTe solar cells, and plan to develop Si solar cells enhanced by growing an epitaxial II-VI junction on the Si junction to create a two-junction solar cell. The prospects for developing novel radically lower-cost and more efficient solar cells are discussed.

9083-37, Session 8

Flexible, lightweight CdTe solar cells on thin glass *(Invited Paper)*

Teresa M. Barnes, Matthew O. Reese, James Burst, William L. Rance, Timothy A. Gessert, Wyatt K. Metzger, National Renewable Energy Lab. (United States); Daniel Meysing, Colin A. Wolden, Colorado School of Mines (United States); Xinghua Li, Pat Cimo, Sean Garner, Corning Incorporated (United States)

Flat-panel CdTe photovoltaic modules are a commercially competitive solar technology due to the low cost of CdTe manufacturing. Until recently, the record efficiency of CdTe cells has lagged behind that of thin-film CIGS, but recent results have demonstrated efficiencies approaching 20%. CdTe will become increasingly more competitive with silicon solar and fossil fueled energy production as the efficiency increases.

CdTe modules and most high-efficiency research devices are made using a "superstrate" configuration. Superstrate devices must be made on a highly transparent material, usually glass, that can withstand high temperatures. This has limited the opportunities for flexible and roll-to-roll production of CdTe because most flexible polymers have low optical transmission and limited thermal stability. New, thin, flexible glasses, such as Corning® Willow® Glass, combine flexibility and amenability with roll-to-roll processing and high optical transmission, high thermal and chemical stability, high electrical resistivity, and the hermeticity of glass. We have made CdTe devices with efficiencies greater than 14% on Willow Glass.

Here, we will discuss device fabrication and performance on this flexible glass. We have made high-efficiency devices using several different front and back contact stacks. These device structures are all processed at high temperatures (550oC – 600oC) using sputtering, evaporation, close-spaced sublimation, and chemical vapor deposition. The devices demonstrate proof of concept for high-efficiency flexible photovoltaics made with high-rate and low-cost deposition processes for applications that require higher specific power or a unique form factor.

9083-38, Session 8

Fundamentals and recent results of super-high-efficiency solar cells *(Invited Paper)*

Masafumi Yamaguchi, Kazuma Ikeda, Yoshio Ohshita, Toyota Technological Institute (Japan)

The photovoltaic (PV) solar energy conversion is expected to become the major clean energy source because further installation of nuclear energy in the world is presumed to be very difficult as a result of the most recent crisis of the Fukushima nuclear power plant in Japan. Really, solar electricity including solar PV is expected to contribute as the main energy with a share of about 20% and 70% in 2050 and 2010, respectively in total energy of the world, according to the World Energy Vision 2100 [1]. To this end, further development of PV science and technology and further deployment of PV power generation systems are very important in addition to international, national and regional government dissemination programs. Especially, very large-scale installation of PV power systems is needed and thus development of ultra-high performance, low cost and highly reliable solar cells is very important as well as development of low cost and long lifetime batteries, highly reliable and intelligent system technologies such as smart grids. The concentrator PV have great potential for very large-scale integration of PV as well as high performance crystalline Si PV.

This paper summarizes fundamental physics of high-efficiency III-V compound semiconductor and multi-junction (MJ) solar cells and their key technologies for realizing higher efficiency. This paper also reviews Japanese research activities for III-V MJ and concentrator solar cells. Concentrator 4-junction or 5-junction solar cells have great potential for realizing super high efficiencies of over 50 %. Lattice-mismatched and III-V-N are thought to be promising materials for realizing more than 50% efficiency. Improvement in the 1-sun efficiency of triple-junction solar cells is also possible. Most recently, new world-record efficiency (37.9%) at 1-sun (AM1.5G) has been realized with inverted epitaxially-grown InGaP/GaAs/InGaAs 3-junction cells by Sharp. 44.4% efficiency has also been demonstrated with InGaP/GaAs/InGaAs 3-junction solar cells by Sharp under the Europe-Japan Collaborative Project on Concentrator PV. It is clear that Japanese group has greatly contributed to development of high efficiency cells.

Concentrator 4-junction or 5-junction solar cells have great potential for realizing super high-efficiency of over 50%. Concentrator PV is expected to contribute as one of major PV as well as the first crystalline Si PV and the second thin-film PV.

9083-39, Session 8

Nanoscale optimization of quantum dot media for effective photovoltaic conversion *(Invited Paper)*

Kimberly A. Sablon, U.S. Army Research Lab. (United States)

To increase the efficiency beyond the Shockley-Queisser limit, the radiation of photons should be matched to the electron transitions and electron processes should be optimized to effectively collect photocarriers in contacts. There are many approaches for nano-engineering of photon and electron states and interaction processes. Possibilities of photovoltaic conversion via impurity bandgap states were studied for more than forty years. Last decade achievements in nanotechnology strongly encourage research aimed towards the development of high efficiency nanomaterials. The main problem of nanostructured materials is enhanced recombination of photocarriers. To address this problem, we proposed a nanoscale engineering of potential profile by quantum dots with built-in charge (Q-BIC). Dot charging is realized by selective doping of the interdot space. Potential barriers around negatively charged dots separate quantum dots (QDs) from the conducting channels along which photoelectrons move to the contacts. These barriers exponentially suppress the capture of photoelectron by QDs. Charging of QD by electrons significantly enhances the multistep electron transitions and hot-electron induced subband transitions. Reduction of the wetting layer suppresses photoelectron capture and decreases corresponding recombination losses. Having been placed in 3 μm base of the single junction, the 1 μm medium of QDs with RWL and electron population of ~3 electron per dot increases the short circuit current by 6.1 mA/cm2 and improves the photovoltaic efficiency by 2.5% compared with the reference cell. In absolute units, the device shows the short-circuit current of 28.1 mA/cm2 and photovoltaic efficiency of 18%. The reduction of the wetting layer, which otherwise accumulates electrons, increases extraction of electrons from QDs due to interaction with hot electrons created by high energy photons. Nanoscale optimization of electron processes by charging of QDs provides wide possibilities for further suppression of recombination and thermalization losses in QD photovoltaic devices.

9083-40, Session 8

Using soft x-rays to look into (buried) interfaces of energy conversion devices *(Invited Paper)*

Clemens Heske, Univ. of Nevada, Las Vegas (United States) and Karlsruher Institut für Technologie (Germany)

The electronic and chemical structure of interfaces is of central importance for understanding and tailoring of materials, chemical processes, and electronic devices. Thus, over the past few decades, enormous experimental (and theoretical) insights into electronic and chemical structures of well-defined model surfaces have been sought and gained by a variety of approaches.

But what if the area of interest is buried, e.g., at an interface? What if no suitable, well-defined, and clean model surfaces are available? And how much do we know about the electronic and chemical structure of liquids or at liquid-solid interfaces?

The purpose of this talk is to demonstrate how a tool chest of soft x-ray spectroscopies (including lab-based techniques and approaches using high-brilliance synchrotron radiation) is uniquely suited to address such questions. The talk will focus on compound semiconductors for thin film solar cells and photoelectrochemical water splitting, and it will be shown how soft x-rays can be utilized to shed light on their electronic and chemical properties.

9083-41, Session 9

Coherent feedback and photonic engineering *(Invited Paper)*

Hideo Mabuchi, Stanford Univ. (United States)

We will describe recent progress in several research projects aimed at demonstrating the utility of coherent feedback in quantum-limited photonic signal processing. We will discuss a cavity QED experiment aimed at demonstrating coherent feedback control of optical bistability, an experiment on coherent feedback control of squeezed light generation in a network of optical parametric oscillators, computational modeling studies of photonic logic components suitable for large-scale fabrication, and theoretical research on circuit architectures for robust optical computation in the quantum noise-limited regime.

9083-42, Session 9

Low-power nonlinear nanophotonic circuits for classical information processing *(Invited Paper)*

Raymond G. Beausoleil, Hewlett-Packard Labs. (United States)

Over the next decade, computers based on CMOS transistors will reach fundamental physical limits that will halt the exponential performance improvements implied by “Moore’s Law.” In particular, the energy required to change the state of an electronic charge-based silicon bit is unlikely to improve significantly as the computer industry reaches the end of the International Technology Roadmap for Semiconductors. Any future information processing technology designed to operate with significantly less power than that of current chips will necessarily rely on a relatively small number of fundamental particles to encode information. In this case, the intrinsic quantum properties of these particles will be difficult to suppress, increasing noise levels and therefore bit error rates. New methods will be needed to harness these quantum properties to allow reliable classical computing and communication. We have begun a basic research project - funded by DARPA under the MesoDynamical Architectures Program - that relies on nonlinear optical effects in complex nanophotonic circuits to help us understand the fundamental physical principles underlying post-Moore’s-Law IT. While it is unlikely that optical computation will be practical for consumer IT applications in the near future, the investigation of coherence in all-optical data processing will enable us to understand the role of feedback-based error correction strategies when computing using a small number (10 to 100) of quantum objects.

9083-43, Session 9

Traveling-wave photon-phonon coupling as the basis for new signal processing technologies *(Invited Paper)*

Peter T. Rakich, Yale Univ. (United States); Jonathan A. Cox, Sandia National Labs. (United States); Heedeuk Shin, Yale Univ. (United States); Zheng Wang, S. Hossein Mousavi, Hui Dong, The Univ. of Texas at Austin (United States); Rob Jarecki, Aleem Siddiqui, Sandia National Labs. (United States); Robert C. Potter, Rockwell Collins, Inc. (United States)

We present progress towards the development of novel hybrid photonic-phononic oscillator technologies in both nanoscale silicon photonics and in fiber optic systems. These systems utilize traveling-wave photon-phonon couplings involving both forward- and backward- stimulated Brillouin scattering processes (SBS). We explore numerous geometries that have enabled large forward-SBS processes in nanoscale silicon waveguides for the first time, and examine new approaches to achieving integrated Brillouin lasers. Through complementary efforts, we also examine systems based approaches to the control and implementation of fiber based Brillouin lasers, in an effort to identify the fundamental noise limitations of Brillouin oscillators as RF sources.

9083-44, Session 9

Coherent signal transduction between photons, microwaves, and spin waves *(Invited Paper)*

Xufeng Zhang, Hong Tang, Yale Univ. (United States)

We demonstrate coherent information transduction between optical, microwave and magnonic carrier in hybrid photonic / magnonic waveguides. Very low loss photonic circuits are patterned from magneto-optic yttrium iron garnet (YIG). The co-localization of spin wave and lightwave leads to very efficient interconversion of light to spin wave and vice versa. The underlying physics responsible for this interconversion will be discussed. We also show electrical field control of spin wave propagation in waveguide structures via spin-obit coupling.

9083-45, Session 10

Self-assembly and programmable materials *(Invited Paper)*

Skylar Tibbits, Massachusetts Institute of Technology (United States)

There is a disciplinary convergence upon us, one that spans from the nano-scale to the human-scale. We are now able to program nearly everything from bits to DNA, proteins, cells, proto-cells, even products, architecture and infrastructure. Programmability and computing are becoming ubiquitous across scales and disciplines. We need to translate these phenomena into solutions for large-scale applications rather than focus only on increasingly smaller-scale technologies At the Self-Assembly Lab, we aim towards the built-environment, from manufacturing, construction, infrastructure and products to develop more adaptive and highly resilient systems. The key to applying this programmability and computational intelligence is human-scale self-assembly and programmable materials. We have demonstrated that self-assembly is scale-independent and have produced prototypes ranging from 1D, 2D, 3D and even 4D Printing aimed at inventing a future of programmable built environments.

9083-46, Session 10

Programmable synthesis and integrated chemical discovery enabled by 3D-printed reactionware *(Invited Paper)*

Lee Cronin, Univ. of Glasgow (United Kingdom)

3D-printing is an emerging technology promising to revolutionize manufacturing processes, transforming the relationship between design and manufacture of functional devices. 3D-printing technologies have been used for the assembly of large scale prototyping, tissue growth scaffolds, biomimetic microvascular systems, and the manufacture of highly specialized electronic devices. One area of science and technology where 3D-printing has so far failed to make a significant impact is in the field of chemical synthesis, despite the vast potential that bespoke, 3D-printed chemical reactors could display for parallel optimisation of reaction sequences, automated synthesis and interrogation of complex interlinked chemical equilibria. Also 3D-printing raises the possibility of liberating chemical syntheses from the expert, exploiting robotic operations for self-contained chemical reactors where the starting materials of a synthetic path are included in the production of the device.

Recent work in our group has developed the concept 3D printing in chemistry with the invention of ‘reactionware’, i.e. reaction vessels that combine reactor and reagents, allowing both chemical and architectural

control of the reaction outcome. This approach could have great benefits in making chemical synthesis more accessible, both to those with no formal training in synthesis, in other laboratory settings such as in a tissue engineering lab, and also in situations where laboratory infrastructure is lacking (such as the developing world). The concept of reactionware, allied to the rapidity and versatility of 3D-printing techniques allows the chemist to seek out entirely new methods of interacting with chemical processes and brings a new dimension to their design. In this talk I will present the application of reactionware to the development of 'digital' synthesis techniques using both batch, flow, mill and microfluidic systems including the realisation of plug and play reactor systems allowing the integration of advanced 'fluidic programming' and also explore the possibility of discovering new classes of molecules, reactions, and developing hybrid biological-synthetic devices for medical applications.

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9083-47, Session 10

3D printed bionic ears *(Invited Paper)*

Manu Sebastian Mannoor, Ziwen Jiang, Princeton Univ. (United States); Teena James, Johns Hopkins Univ. (United States); Yong Lin Kong, Karen Malatesta, Winston W. O. Soboyejo, Naveen Verma, Princeton Univ. (United States); David H. Gracias, Johns Hopkins Univ. (United States); Michael C. McAlpine, Princeton Univ. (United States)

The ability to three-dimensionally interweave biological tissue with functional electronics could enable the creation of bionic organs possessing enhanced functionalities over their human counterparts. Conventional electronic devices are inherently two-dimensional, preventing seamless multidimensional integration with synthetic biology, as the processes and materials are very different. Here, we present a novel strategy for overcoming these difficulties via additive manufacturing of biological cells with structural and nanoparticle derived electronic elements. Specifically, our approach attains three dimensional integration of electronics with biological tissues via simultaneous 3D printing of functional electronic components with biological cells in the precise anatomic geometry of human organs, and thus enables the creation of true bionic organs in their form and function. As a demonstrative system, we generated a bionic ear via 3D printing of a cell-seeded hydrogel matrix in the anatomic geometry of a human ear, along with an intertwined conducting polymer consisting of infused silver nanoparticles. This allowed for in vitro culturing of cartilaginous tissue around an inductive coil antenna in the ear, which subsequently enables readout of inductively-coupled signals from cochlea-shaped electrodes. The printed ear exhibits enhanced auditory sensing for radio frequency reception, and complementary left and right ears can listen to stereo audio music. Overall, our approach suggests a means to intricately merge biologic and nanoelectronic functionalities via 3D printing.

9083-48, Session 10

Moving toward multifunctional additive manufacturing *(Invited Paper)*

Christopher J. Tuck, The Univ. of Nottingham (United Kingdom)

This paper discusses the current activities of the EPSRC Centre for Innovative Manufacturing in Additive Manufacturing (AM) and the efforts towards making multi-material Additive Manufacturing and 3D Printing a reality for the development of novel sensing and material systems. The paper will introduce the concepts of 3D Printing for multi-functional components that attempts to produce "active" systems rather than the current state of the art of "passive components". The paper will specifically discuss the current capabilities of inkjet and higher resolution AM systems under development at the EPSRC Centre and the challenges of developing new and more applicable materials for these manufacturing techniques with particular regard to developing electronic, optical and biological materials that can be integrated into structural systems.

This paper will highlight the current efforts of developing multi-material 3D Printing systems with both micro (3D jetting) and nano-scale resolutions (multi-photon polymerisation) and the requirements to preferentially deposit and convert different material types in order to tailor a systems response to external perturbations. The paper will provide a detailed examination of the problems with current "active" inks for multi-material 3D printing, i.e. nano-flake inks and provide alternatives for future research and increased performance.

9083-49, Session 10

3D printing of liquid metals for stretchable and flexible conductors *(Invited Paper)*

Michael Dickey, Collin Ladd, John F. Muth, Ju-Hee So, North Carolina State Univ. (United States)

The ability to 3D print metal is important for rapid prototyping of functional electronic devices using additive manufacturing techniques. Metal parts may be 3D printed by selectively sintering layers of metal dust one layer at a time, though such a method requires expensive laser writers or electron-beam systems to induce high local temperature excursions to fuse the metallic powder, which is not compatible with polymers, organics, and biological species. This talk will discuss new methods to directly print a micromoldable liquid metal into 3D structures at room temperature and embed it in functional polymers to create conductors that are soft, self-healing, and ultra-stretchable. The metal is a gallium-based metal alloy that is a low-viscosity liquid at room temperature with low toxicity and negligible volatility. Despite the large surface tension of the metal, it can be molded into non-spherical shapes due to the presence of an ultra-thin oxide skin that forms on its surface. The metal can be patterned by injection into microchannels or by direct-write techniques. We will discuss three different, yet complimentary methods to direct-write the method including extrusion, stacking of droplets, and the use of pressure to create stable fibers of the liquid metal. Because it is a liquid, the metal is extremely soft and flows in response to stress to retain electrical continuity under extreme deformation. By embedding the metal into elastomeric substrates, it is possible to form soft electrodes and optical components, stretchable antennas, and ultra-stretchable wires that maintain metallic conductivity up to ~800% strain.

9083-50, Session 11

Some recent developments in stretchable and flexible electronics *(Keynote Presentation)*

John A. Rogers, Univ. of Illinois at Urbana-Champaign (United States)

Biology is soft, curvilinear and transient; modern silicon technology is rigid, planar and everlasting. Electronic systems that eliminate this

profound mismatch in properties will lead to new types of devices, capable of integrating non-invasively with the body, providing function over some useful period of time, and then dissolving into surrounding biofluids. Recent work establishes a complete set of materials, mechanics designs and manufacturing approaches that enable these features in a class of electronics with performance comparable to that of conventional wafer-based technologies. This talk summarizes the key ideas through demonstrations in skin-mounted 'epidermal' monitors, advanced surgical tools and bioresorbable electronic bacteriocides.

9083-51, Session 11

Adapting MEMS technology to soft, bioelectronics interfaces *(Invited Paper)*

Stephanie P. Lacour, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

Soft, bioelectronics interfaces are broadly defined as microfabricated devices with mechanical properties suited to comply with biological tissues. There are many challenges associated with the development of such technology platforms. Simultaneously one must achieve reliable electronic performance, thermal and environmental stability, mechanical compliance, and biocompatibility. Materials and system architecture must be designed such that mechanical integrity and electrical functionality is preserved during fabrication, implementation and use of the interface.

Depositing and patterning conventional device materials, ranging from inorganic to organic thin films as well as nanomaterials, directly onto soft elastomeric substrates enable electronic devices with enhanced mechanical flexibility. Success in fabrication also relies on a careful design of the mechanical architecture of the soft interface to minimize mechanical stresses in the most fragile materials.

Using examples from our work on soft, implantable neural electrodes as well as prosthetic sensory skin, we will illustrate how well-established microfabrication technology can be adapted to polymeric, elastic materials to produce sensors, thin film transistors and electrode arrays, which can reliably sustain cyclic macroscopic deformations, and this in a wet, in vivo environment.

9083-52, Session 11

Advanced flexible electronics: challenges and opportunities *(Invited Paper)*

Stephen W. Bedell, IBM Thomas J. Watson Research Ctr. (United States)

This presentation will give an overview of various techniques in pursuit presently to enable flexible electronics applications. Some examples of currently practiced techniques include Smartcut, Epitaxial lift-off, laser ablation, and grind and etch-back. Although successful implementation of these techniques for flexible electronics has been demonstrated, their application space is not extendable to a wide spectrum of products due to a number of reasons: (i) varying thickness requirements of the flexible layer, (ii) low thermal budget (preferably room temperature) of the flexible layer process, (iii) manufacturability, and (iv) cost of ownership. We have reported previously on a layer transfer technique referred to as controlled spalling technique (CST) which overcomes the limitations described above [1]. The overview will focus on the following enabling attributes of CST for flexible electronics: (i) low cost of ownership, (ii) its applicability at any process step during device fabrication from starting substrates to completed devices, (iii) thickness control in the range of angstroms to tens of microns, (iv) no dependence on any substrate size or shape (v) applicability to any brittle material whether crystalline or amorphous. Successful implementation of CST in fabricating high-efficiency flexible GaAs-based solar cells, as well as release of 22 nm CMOS Si circuits will be described [2]. Finally, more recent application of CST in fabricating functional flexible multi-quantum well (MQW) based InGaN/GaN epitaxial LED will be discussed [3]. It will be shown that CST not only enables flexible electronic circuits with unprecedented level of complexity but also allows re-use of substrates from which flexible electronic products have been removed.

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9083-53, Session 11

High performance Bio-integrated Devices *(Invited Paper)*

Dae-Hyeong Kim, Jongha Lee, Minjoon Park, Seoul National Univ. (Korea, Republic of)

Research in nanomaterials and microelectronics technologies have driven important advances in healthcare in recent years. However, the mechanical and geometrical constraints inherent in all standard forms of rigid electronics impose unique integration and therapeutic delivery challenges for wearable medical devices. Here, we describe novel materials and design constructs for multifunctional wearable electronic devices, which incorporate arrays of single crystal silicon and inorganic solid-state sensors (e.g. strain gauges, temperature sensors) and actuators (e.g. resistive heaters), coupled with important new approaches for integrating nonvolatile memory with uniform-sized nanoparticles (for portable data storage with low power consumption) and nanoparticle-based drug release mechanisms (for transdermal drug delivery). Quantitative analyses of heat-transfer, drug-diffusion, and electronic performances of these systems during mechanical deformations and under moisturized circumstances validate the individual components, thereby enabling system-level functions. These systems combine advances in sensing, data storage, and drug-based feedback therapy to create new opportunities and directions in translational medicine.

9083-54, Session 11

Transformational electronics: A powerful way to revolutionize our information world *(Invited Paper)*

Muhammad M. Hussain, Jhonathan P. Rojas, Galo A. Torres Sevilla, Mohamed T. Ghoneim, Aftab M. Hussain, Sally M. Ahmed, Joanna M. Nassar, Rabab R. Bahabry, Maha Nour, Arwa T. Kutbee, Amal M. AlAmri, King Abdullah Univ. of Science and Technology (Saudi Arabia); John A. Rogers, Univ. of Illinois at Urbana-Champaign (United States)

With the emergence of cloud computation, we are facing the rising waves of big data. It is our time to leverage such opportunity by increasing data usage both by man and machine. For us we need ultra-mobile computation with high data processing speed, ultra-large memory, energy efficiency and multi-functionality. Additionally, we have to deploy energy-efficient multi-functional 3D ICs for robust cyber-physical system establishment. To achieve such lofty goal we have to mimic human brain which is inarguably the world's most powerful and energy efficient computers. Brain's cortex has folded architecture to increase surface area in an ultra-compact space to contain its neuron and synapses. Therefore, it is imperative to overcome two integration challenges: (i) finding out a low-cost 3D IC fabrication process and (ii) foldable substrates creation with ultra-large-scale-integration of high performance energy efficient electronics. Hence, we show a low-cost generic batch process based on trench-protect-peel-recycle to fabricate rigid and flexible 3D ICs as well as high performance flexible electronics. As of today we have made every single component to make a fully flexible computer including non-planar state-of-the-art FinFETs. Additionally we have demonstrated various solid-state memory, movable MEMS devices, energy harvesting and storage components. To show the versatility of our process, we have extended our process towards other inorganic semiconductor substrates such as silicon germanium and III-V materials. Finally, we report first ever fully flexible programmable silicon based microprocessor towards foldable brain computation and wirelessly programmable stretchable and flexible thermal patch for pain management for smart bionics.

9083-55, Session 11

Mechanics of flexible electronics and photonics based on inorganic micro- and nanomaterials *(Invited Paper)*

Nanshu Lu, The Univ. of Texas at Austin (United States)

Flexible electronics and photonics are providing revolutionary solutions for communication, energy, and health care. While some of the organic electronic and photonic materials are intrinsically deformable and low cost to manufacture, their performance and chemical stabilities are yet to match well-established inorganic materials. Strategies for high performance flexible electronics and photonics must overcome challenges associated with the intrinsic stiffness and brittleness of inorganic functional materials. The fundamental understandings of the mechanical interactions between the stiff functional materials and the compliant supporting substrates have led to largely enhanced deformability and functionalities of the device systems. This talk discusses the recent development of the mechanics and fabrication strategies toward a wide variety of flexible electronics and photonics. Three examples of flexible devices involving three types of inorganic materials will be presented to manifest the ubiquitous power of such mechanistic understandings. First, silicon-based ultra-thin, ultra-soft electronic tattoos are created to achieve conformal contact and compatible deformation with bio-tissues for sensing and stimulation. Second, flexible transistors based on few layer molybdenum disulfide (MoS2) will demonstrate combined high electronic performance and large bendability. Bendable photonic devices based on high-refractive index chalcogenide glass will be employed to illustrate the optoelastic coupling during bending.

9083-56, Session 11

Two-dimensional atomic sheets for heterogeneous flexible high-frequency and low-power nanoelectronics *(Invited Paper)*

Deji Akinwande, The Univ. of Texas at Austin (United States)

Two-dimensional atomic sheets have emerged as near ideal nanomaterials to overcome the long running challenge of achieving Si CMOS like performance on soft substrates at scales that can be suitable for large integration. For instance, the high mobility and velocity accessible in monolayer graphene affords GHz analog transistor devices while the large bandgap of graphene's semiconducting analogues (MoS2 and similar dichalcogenides) naturally lead to near ideal digital transistors with high on/off current ratio and low subthreshold slope while sustaining mobilities much larger than organic semiconductors or amourphous bulk semiconductors. Together, these physically similar atomic layers with vastly different electronic properties can serve as the electronic platform for low-power digital, high-speed mixed-signal, and high-frequency analog transistor building blocks for flexible nanoelectronic systems.

In this work, we present the latest findings on the coupled device mechanics and device physics of 2D semiconducting sheets. The device mechanics on plastic substrate as a function of tensile strain reveal that dielectric cracking is responsible for off-current degradation while buckling is largely responsible for on-current degradation. Optimized dielectric patterning for strain relaxation was found to improve device reliability at low bending radius. In addition, we report the highest mobilities and cut-off frequencies in state-of-the-art graphene transistors based on inductively-heated chemical vapor synthesized graphene. Our results collectively indicate that graphene is the most suitable material for flexible radio-frequency transistors while MoS2 is ideal for low-power flexible transistors.

9083-57, Session 11

High-performance flexible microwave passives on plastic *(Invited Paper)*

Zhenqiang Ma, Univ. of Wisconsin-Madison (United States); Weidong Zhou, The Univ. of Texas at Arlington (United States)

Microwave circuits have been traditionally fabricated on rigid substrates, either on rigid semiconductor wafers or on circuit boards. These circuits lack mechanical flexibility and thus limit their use under certain circumstances. Very low-cost plastics are suitable substrates for flexible microwave application for their mechanical flexibility and acceptable radio-frequency (RF) loss at fairly high frequencies. In this talk we present the RF characterizations of flexible plastic substrates and the design and fabrication of high-performance microwave passives, including flexible inductors and flexible capacitors, that are fabricated on plastic substrates. Relevant active RF devices and circuits fabrication technologies will also be presented

9083-58, Session 11

Arthropod eye-inspired digital camera with unique imaging characteristics *(Invited Paper)*

Jianliang Xiao, Univ. of Colorado at Boulder (United States); Young Min Song, Yizhu Xie, Viktor Malyarchuk, Univ. of Illinois at Urbana-Champaign (United States); Inhwa Jung, Kyung Hee Univ. (Korea, Republic of); Zhuangjian Liu, A*STAR Institute of High Performance Computing (Singapore); Chaofeng Lu, Zhejiang Univ. (China); Rak Hwan Kim, Univ. of Illinois at Urbana-Champaign (United States); Rui Li, Dalian Univ. of Technology (China); Kenneth B. Crozier, Harvard Univ. (United States); Yonggang Huang, Northwestern Univ. (United States); John A. Rogers, Univ. of Illinois at Urbana-Champaign (United States)

In nature, arthropods have a remarkably sophisticated class of imaging systems, with a hemispherical geometry, a wide-angle field of view, low aberrations, high acuity to motion and an infinite depth of field. There are great interests in building systems with similar geometries and properties due to numerous potential applications. However, the established semiconductor sensor technologies and optics are essentially planar, which experience great challenges in building such systems with hemispherical, compound apposition layouts. With the recent advancement of stretchable optoelectronics, we have successfully developed strategies to build a fully functional artificial apposition compound eye camera by combining optics, materials and mechanics principles. The strategies start with fabricating stretchable arrays of thin silicon photodetectors and elastomeric optical elements in planar geometries, which are then precisely aligned and integrated, and elastically transformed to hemispherical shapes. This imaging device demonstrates nearly full hemispherical shape (about 160 degrees), with densely packed artificial ommatidia. The number of ommatidia (180) is comparable to those of the eyes of fire ants and bark beetles. We have illustrated key features of operation of compound eyes through experimental imaging results and quantitative ray-tracing-based simulations. The general strategies shown in this development could be applicable to other compound eye devices, such as those inspired by moths and lacewings (refracting superposition eyes), lobster and shrimp (reflecting superposition eyes), and houseflies (neural superposition eyes).

9083-59, Session 11

Soft, stretchable bio-integrated systems for continuous health monitoring *(Invited Paper)*

Roozbeh Ghaffari, Yung-Yu Hsu, Xianyan Wang, Pinghung H. Wei, Milan Raj, Mitul Dalal, Briana Morey, Bryan Keen, MC10, Inc. (United

States)

Mechanically invisible wearable devices that monitor physiological activity and deliver actuation represent the next frontier in personalized medicine. However, fundamental technical challenges exist in achieving intimate mechanical coupling between existing classes of rigid electronics with soft biological substrates. This gap in mechanics leads to signal degradation due to poor physical contact and potential discomfort for the subject. Here we describe new materials, mechanics and design strategies for wearable devices with mechanical properties comparable to biological tissue. These systems exploit stretchable networks of conformal sensors (electrodes, temperature sensors, and accelerometers) and associated circuitry (bare die microcontroller, memory, voltage regulators, wireless communication modules) embedded in ultrathin, elastomeric substrates. Quantitative analyses of sensor performance and mechanics under stress illustrate the ability to mechanically couple with soft tissues in a way that is invisible to the user. Representative examples of these soft biointegrated systems can be applied for continuous sensing of cardiac and muscle activity in hospital settings, and for low-cost transient data capture for ambulatory care.

9083-60, Session 12

From wakes to wings: Using a multi-fidelity approach to design flapping wings *(Invited Paper)*

David J. Willis, Univ. of Massachusetts Lowell (United States)

The biologically-inspired flight design space is large due to the significant number of design parameters that can be tuned to achieve efficient results. In this paper a multi-fidelity approach for narrowing the efficient flight design space is presented. Lower-fidelity methods based on aerodynamics wakes and coupled, efficient inviscid-viscous flow are used to understand the design space. These methods include the author's wake-only energetics method which is based on a wake-only aerodynamics analysis (Hall et al., AIAA Journal 2001) to predict the overall kinematics of efficient flight (Salehipour & Willis, Journal of Theoretical Biology, 2013). The optimal vorticity wake distributions can then be used as a basis or target distribution for the inverse design of wings to achieve efficient flight. We will present an in-house, quasi-inverse doublet lattice method that is being used for the wing inverse shape design process (Willis & Persson, Submitted to AIAA Journal). The results of this analysis are a time dependent optimal wing shape. Higher fidelity methods are subsequently used to confirm these predictions (Persson, Willis, 2012, IJNME). Examples of computationally designed, optimal energetics flapping wings will be presented.

9083-61, Session 12

Characterization and enhancement of micro brushless DC motor response *(Invited Paper)*

Joseph K. Conroy, U.S. Army Research Lab. (United States); Andrew Kehlenbeck, Univ. of Maryland, College Park (United States); James S. Humbert, Univ. of Maryland, College Park (United States)

Micro-scale motors are a ubiquitous method of actuation within small-scale robotic systems. In particular, flying vehicles typically employ several of these motors for propulsion that require reliable operation over the full range of achievable speeds. In addition to time-dependent linear dynamics, these motors exhibit a nonlinear relationship between the steady state input current, usually taken as an average, and the steady state output rotational speed. These motors can often be well modeled in practice as a Hammerstein type system, comprised of the cascade of a static memoryless nonlinearity followed by a linear dynamic model. Without accounting for this nonlinearity, the ultimate closed loop performance of the robotic vehicle can be impacted by actuation that is not within a small linearized range.

Despite this drawback, these motors are typically used directly within small-scale applications without any closed loop control. This research examines the open loop characteristics that typify small scale motor response and evaluates the extent to which response can be improved via practical implementation of classical closed loop control and a static estimate of the nonlinearity. Finally, an adaptive controller is designed that permits a model of the unknown, memoryless nonlinear function to be dynamically identified and accounted for.

9083-62, Session 12

Power and weight considerations in small, agile quadrotors *(Invited Paper)*

Yash Mulgaonkar, Michael Whitzer, Univ. of Pennsylvania (United States); Brian Morgan, Christopher M. Kroninger, Aaron M. Harrington, U.S. Army Research Lab. (United States); Vijay Kumar, Univ. of Pennsylvania (United States)

Small aerial vehicles (under 1 meter and 5 kilos) are more agile and maneuverable than human scale flying vehicles. However, the size, weight and power constraints in developing autonomous Micro Aerial Vehicles (MAVs) are significant. Our main interest in this paper is in MAVs that can easily enter buildings and navigate indoor environments. Quadrotors (and other multi-rotor vehicles) are particularly attractive because of the simplicity in design (rigid frame with four motors, with light weight, rigid blades) and the low fabrication cost. Accordingly, we focus on design considerations and scaling arguments for small quadrotors with an eye toward autonomous operation.

In this paper, we first explore scaling arguments for mass, inertia, lift, and drag as the characteristic length (e.g. the largest linear dimension) is decreased. We show experimental results that suggest that the Froude scaling paradigm, which says that the rotor speeds scale inversely with the square root of the characteristic length, is valid for quad rotors between 0.1 m to 0.75 m in diameter. This in turn suggests that the angular acceleration scales inversely with length.

Second, we study the effects of the length scale on masses and inertias associated with the different components: frame, motors, control boards, sensors and batteries. This allows us to formulate design guidelines to minimize inertia which in turn allows us to maximize accelerations for a given set of motors.

Third, we report studies on a range of Lithium Polymer batteries, the ideal energy source for MAVs, showing candidate batteries and their performance in terms of specific power and specific energy.

Finally, we describe the power and energy consumption for different quadrotors and explore the dependence on size and mass, and on the candidate maneuvers chosen for the study.

9083-63, Session 12

Endurance bounds of aerial systems *(Invited Paper)*

Aaron M. Harrington, U.S. Army Research Lab. (United States)

Handheld aerial systems are of interest for various defense, law enforcement, and commercial applications. At the scale of a hand held system, questions exist about the relative merits of various traditional (fixed and rotary wing) and biological (insect and avian-like flapping) configurations. Currently, there is no clear method for determining the applicability of a particular configuration to optimally achieve a specified mission scenario. Therefore, the current study explores the bounds of endurance for each of the various traditional and biological vehicle configurations. The performance space of vehicle size, weight and speed for hover and non-hover capable configurations is modeled. Classically developed solutions capture the minimum induced power. A scaling law is proposed which captures the minimum profile power required for force generation. The various subsystems are modeled and the impact of their efficiency with scale, and requirements for integration are incorporated in the endurance predictions. Results indicate that the same aerodynamic endurance bounds likely apply to the biological and traditional configurations, but from a full systems perspective, traditional configurations are preferred above insect size scales.

Alternative desirable design objectives beyond maximizing endurance drive other trade-off considerations, in particular, a need for high aircraft agility, which is an area for future study.

9083-64, Session 12

Autonomous charging to enable long-endurance missions for small aerial robots *(Invited Paper)*

Yash Mulgaonkar, Vijay Kumar, Univ. of Pennsylvania (United States)

The past decade has seen an increased interest in Autonomous Micro Aerial Vehicles (MAVs). MAVs are agile, capable of maneuvering in constrained three-dimensional environments and able to perform tasks too difficult or dangerous for humans and able to navigate and perform missions which ground robots cannot. Rotary wing MAVs such as quadrotors, can operate in confined spaces, hover at a given point in space and perch or land on a flat surface. This makes the quadrotor a very attractive aerial platform with tremendous potential.

The potential of these MAVs is severely limited by the constraints on the flight time due to limited battery capacity. Current battery technology is limited in terms of the available energy density. Moreover, quadrotors have a disadvantage, that they consume several hundred watts of power per kilo. Thus, small MAVs (0.1 - 0.5 m in diameter) are unable to operate for more than 10-15 minutes.

Our solution to this problem consists of automating the battery recharging process, creating autonomous MAVs that can recharge their on-board batteries without any human intervention and by employing a team of MAVs to substantially increase the overall mission time.

In this paper, we describe the hardware necessary for automated charging, and provide experimental results that demonstrate how we successfully addressed and solved the challenges of contact oxidation and sparking. We develop an algorithm for persistent surveillance in which each robot monitors its battery level, automatically navigates to an available charging station when necessary, and is immediately replaced by a fully charged robot to continue the surveillance task. The scalability of this algorithm is demonstrated by simulating a persistence surveillance task for 10 MAVs and charging stations. Finally, we show experimental results in which, this system was used to perform a 9.5 hour persistent surveillance mission. We also demonstrate applications to a construction task in which cubic structures are assembled, showing a three-fold increase in effective mission time.

9083-65, Session 13

MEMS-based approaches for miniature power supply applications *(Invited Paper)*

Sarah S. Bedair, Christopher D. Meyer, Jeffrey S. Pulskamp, Brian Morgan, Ronald G. Polcawich, U.S. Army Research Lab. (United States); Christopher Dougherty, Xue Lin, David Arnold, Rizwan Bashirullah, Univ. of Florida (United States); Iain Kierzewski, Nathan Lazarus, Joel Martin, Brian Power, U.S. Army Research Lab. (United States)

There are a number of applications motivating the need for ultra-compact and efficient power supplies. These applications include distributed sensors, portable electronics, and future mobile microsystems, which are envisioned to range in size from the centimeter scale down to the millimeter scale. Such future systems have extreme weight and power constraints, and motivate complete mm-scale power supplies. High switching frequencies in the 10's to 100's MHz range enable the scaling down of the electrical passive size, which dominates the power converter system size. This paper will highlight progress and provide an overview of the U.S. Army Research Laboratory's research in the area of chip-scale power converters. The high-performance, chip-scale passives are enabled by MEMS-based devices, including thin-film piezoelectric transformers, inductors, and capacitors. Specifically, the utility of MEMS electromechanical transformers—which offer high power densities, high voltage isolation, and low electromagnetic noise—will be discussed. Such MEMS piezoelectric transformers have resulted in performance characteristics of 6:1 open-circuit voltage gain, 60% peak efficiency, and device power densities as high as 10 W/mm3 at 50 MHz. Furthermore, progress in the area of CMOS switched-capacitor bi-directional converters and their successful powering of mm-scale robotic wings will also be presented. This fully integrated converter was implemented in a 0.13μm 1.2V/3.3V triple-well CMOS process and provided a peak output voltage of ~10V. In addition, the integration of the high performance passives in a single monolithic process, as well as the heterogeneous integration of the active components with electrical passives, will also be highlighted.

9083-66, Session 13

Power management for small scale systems *(Invited Paper)*

Christopher D. Meyer, Sarah S. Bedair, Brian Morgan, U.S. Army Research Lab. (United States); David Arnold, Univ. of Florida (United States); Nathan Lazarus, Iain Kierzewski, U.S. Army Research Lab. (United States)

Contemporary electronic systems often contain multiple power circuits to support the unique power conversion or conditioning needs of various sources and loads, and each of these power circuits is implemented with a handful of parts soldered onto the printed circuit board. As greater levels of functionality are demanded within diminishing size and weight allowances, power management will increasingly be required through highly miniaturized power converters that are more tightly integrated into single-package solutions or even directly integrated onto the points of source and load. Experimental converters have demonstrated great potential in switching at very high frequencies (100+ MHz) to reduce the size of the requisite passive storage elements (inductors, transformers, and capacitors) to values that may be suitable for in-package or on-chip integration. However, integrating the passives into the same package as the active switching and control circuitry remains a significant challenge due to material incompatibility and inadequate performance of the passives.

This paper presents the application of Micro-Electro-Mechanical Systems (MEMS) fabrication processes to create high density passive components. The components are optimized for high performance at hundreds of MHz through the use of thick copper traces, intricate three-dimensional designs, and the ability to integrate dielectric and ferromagnetic nanoparticle materials. The capability of detaching the passives from the fabrication wafer is demonstrated to enable the MEMS passives substrate to further serve directly as a routing platform for full integration of all power components into a single-package solution.

9083-67, Session 13

High-specific energy and specific power aluminum/air primary battery for micro-air-vehicles *(Invited Paper)*

Andrew Kindler, Lawrence Matthies, Jet Propulsion Lab. (United States)

Micro air vehicles require an energy source with extremely high specific energy (watt-hrs/kg) and extremely high specific power (watts/kg) in order to achieve a flying time of about 1 hour. For most micro air vehicle applications, this means 300 – 550 watt-hrs/kg and 300 -550 watts/kg. At present, no existing cell chemistry can meet this dual requirement. Among commercial cells the Li-Ion cell, is currently the closest match to the above requirements. Like all batteries, the usable energy in a Li-Ion battery is dependent on the discharge rate, however a reasonable point of reference is about 150-200 watt-hrs/kg at the cell level, with a specific power up to 200 watts/kg. Somewhat better performance is available from Li/S cells, but this technology is semi-commercial and is known to have poor shelf life. An alternative technology, not currently commercial, is the Al/Air cell.

This cell can be shown to be capable of about 500 watt-hrs/kg and 500 watts/kg. Because the air electrode extracts oxygen from the ambient air, one of the two cell reactants does not have to be carried on board. This accounts in part for the superior performance. The Al/air cell has some well known shortcomings, but these can be addressed by the application of suitable technology to modify both the air and aluminum electrode, as wellas an adaptation of the cell to take advantage of the unique operating environment. In this talk, the design of an Al/Air is presented with a discussion of how the technical issues can be overcome.

9083-68, Session 13

Thermophotovoltaic and thermoelectric portable power generators *(Invited Paper)*

Walker Chan, Massachusetts Institute of Technology (United States); Christopher M. Waits, U.S. Army Research Lab. (United States); Marin Soljacic, Massachusetts Institute of Technology (United States); John D. Joannopoulos, MIT Institute for Soldier Nanotechnologies (United States); Ivan Celanovic, Massachusetts Institute of Technology (United States)

The quest for developing clean, quiet, and portable high-energy-density, and ultra-compact power sources continues. Although batteries offer a well-known solution, limits on the chemistry developed to date constrain the energy density to 0.2 kWh/kg, whereas many hydrocarbon fuels have energy densities closer to 12 kWh/kg. The fundamental challenge remains: How efficiently and robustly can these widely available chemical fuels be converted into electricity in a millimeter to centimeter scale systems? Here we explore two promising technologies for high-energy density power generators, based on statically converting heat into electricity, namely thermophotovoltaics (TPV) and thermoelectrics (TE). TPVs present an extremely appealing approach for small-scale power sources due to the combination of high power density limited ultimately by Planck blackbody emission, multifuel operation due to the ease of generating heat, and a fully static conversion. We will present preliminary experimental results a proof of concept microthermovoltaic (?TPV) system, that validates the theoretical foundation and paves the way toward a new breed of ultra-high energy-density, high efficiency, power sources. TEs on the other hand are very promising candidate for very-high energy density and extremely robust power generator at small scales. This combined with large fundamental research to improve thermoelectric materials warrants serious consideration of TE generators. We will present some previous work done in the TE field. In addition we will outline the common technological barriers facing both approaches, as well as outline the main differences. Performance for state-of-the-art research generators will be compared as well as projections for future practically achievable systems.

9083-69, Session 14

Self-assembled nanostructures as templates for patterned surfaces with non-microelectronic applications *(Keynote Presentation)*

Michael A. Morris, Univ. College Cork (Ireland)

This presentation will commence with a brief overview of block copolymer microphase separation summarizing progress to date. In particular, the talk will focus on how the patterns formed can be transferred to a surface to form a chemical or engineering pattern. This to surface engineering using methods such as: pattern transfer through the use of the polymer material as on-chip etch match, templating and selected area deposition will be described. These techniques have direct relevance to integrated circuit manufacture as a possible alternative to UV photolithography and much work has focussed in areas such as ultra-low defect densities and pitch/feature sizes. However, block copolymer approaches to surface patterning might have relevance in many other application areas since the afford the promise of delivering low cost, practical solutions to nanopatterning over large substrate areas.

In this talk we will detail the use of these to create antimicrobial surfaces, sensor structures, surfaces for heat transfer, chromatography media and for bioengineered substrates. We will illustrate several examples of these applications and describe, in detail, how these can be used to create smart food packaging, processing and storage materials and describe results of antimicrobial tests as well as shelf-life improvements. The nanotoxicology of these materials will also be discussed.

Finally, we will outline the challenges in delivering potential technologies to market. These challenges include:-

a) Developing effective coating methods for complex shapes.

b) Effective, rapid, scale-intensive process methods that avoid e.g. complex plasma etching, pre-patterning, process regularity over very large areas and complex shapes.

c) Extension of feature size range from nanometre to micron.

d) Generation of non-simple shapes, novel material compositions and substrate types.

9083-70, Session 14

Engineering material properties using block copolymer self-assembly *(Invited Paper)*

Atikur Rahman, Antonio Checco, Matthew Eisaman, Charles T. Black, Brookhaven National Lab. (United States)

Block copolymer thin films provide a robust method for generating patterns at 10 nanometer length scales over arbitrarily large areas. A significant advantage of such block copolymer-based patterning is its ease of integration with all other aspects of traditional thin-film processing, including plasma-based etching and metallization. Because of the dearth of other high resolution patterning options, block copolymers are under intense scrutiny by the semiconductor electronics industry for lithography enhancement – an application with extreme demands on pattern uniformity.

However, such process compatibility ensures a host of other application opportunities in designing material properties through control of their nanostructure. For example, we will describe our recent use of block copolymer self assembly in engineering broadband omnidirectional anti-reflecting surfaces for solar device applications. Precisely controlling surface texture through block copolymer-based patterning can also render a material superhydrophobic, and able to remain water-repellent during droplet impacts at speeds in excess of 10 meters per second.

9083-71, Session 14

Patterning of magnetic nanostructures using Si-containing block copolymers *(Invited Paper)*

Caroline A. Ross, Massachusetts Institute of Technology (United States)

The microphase separation of block copolymer films produces periodic nanoscale patterns with feature sizes of a few nm and above, and has been proposed as a method for extending microelectronic fabrication beyond the limits of optical lithography. To control the long range order of the microphase separation, and to produce patterns with designed aperiodic features, templating strategies based on substrate topography have been developed in combination with modeling using self consistent field theory. The structures formed by self-assembly are governed by commensurability between the template and the equilibrium period of the block copolymer. The templating of complex patterns such as 3D cross-point structures from bilayer films of a diblock copolymer, and arrays of rings, square-symmetry posts and Archimidean tiling patterns from linear or star triblock terpolymers will be described. Examples of pattern transfer and applications to nanoscale magnetic device fabrication will be discussed.

9083-72, Session 14

Soft matter design principles for inorganic photonic nanoarchitectures in photovoltaics, colorimetric sensing, and self-cleaning antireflective coatings *(Invited Paper)*

Stefan Guldin, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

The self-assembly of soft matter, such as block copolymers or colloids, allows fine tuning of structure formation on the 10 - 500 nm length scale and therefore enables to design materials with tunable optical response. In my talk I want to present strategies on how to exploit these formation principles to assemble inorganic nanoarchitectures with distinct optical properties.

Control over sub-wavelength properties, such as pore dimensions, pore volume and film thickness of the resulting inorganic films enables the stacking of individual mesoporous layers into a multilayer lattice of alternating high and low refractive index - a mesoporous Bragg reflector [1]. Spontaneous micellisation of an adequate block copolymer system and assembly into a regular lattice-type represents effectively the densest packing of pores, yielding refractive indices as low as 1.13. Loading of the inverse-opal type network with TiO2 nanocrystals results in an optical coating that meets phase and amplitude conditions for interference-based antireflectivity on glass or plastic substrates and maintains its functionality by photocatalytic self-cleaning [2]. The combination of block copolymer and colloidal self-assembly allows to design an TiO2 electrode architecture, where a high surface area mesoporous underlayer is coupled to an optically and electronically active three dimensional photonic crystal with strong effects on light harvesting of the overall photovoltaic construct [3]. Finally I want to outline further efforts of the group towards self-assembled photonic materials, such as the possibilities of using highly ordered BCP morphologies with chiral symmetry for novel optical metamaterials [4].

[1] “Tunable mesoporous Bragg reflectors based on block-copolymer self-assembly” - S. Guldin, M. Kolle, M. Stefik, R. Langford, U.Wiesner, U. Steiner, Advanced Materials, vol. 23, no. 32, pp. 3664-3668, 2011.

[2] “Self-cleaning antireflective optical coatings” - S. Guldin, P. Kohn, M. Stefik, J. Song, G. Divitini, C. Ducati, U. Wiesner, U. Steiner, submitted.

[3] “Dye-sensitised solar cell based on a 3D photonic crystal” - S. Guldin, S. Hüttner, M. Kolle, M. Welland, P. Müller-Buschbaum, R. Friend, U. Steiner, N. Tetreault, Nano Letters, vol. 10, no. 7, pp. 2303-2309, 2010.

[4] “A 3D optical metamaterial made by chiral self-assembly” - S. Vignolini, N.A. Yufa, P.S. Cunha, S. Guldin, I. Rushkin, M. Stefik, K. Hur, U. Wiesner, J.J. Baumberg, U. Steiner, Advanced Materials, vol. 24, no. 10, pp. OP23-OP27, 2012.

9083-73, Session 14

Directed self-assembly for extending patterning capability *(Invited Paper)*

Joy Y. Cheng, IBM Research - Almaden (United States)

High-volume and high-resolution patterning capability are desirable for many novel devices. Conventional lithography technologies is either limited by resolution (such as 193nm immersion lithography) or by throughput (such as electron-bean lithography). Directed self-assembly (DSA) of polymers, which combines self-assembled polymers and lithographically-defined directing prepatterns, provides a cost-efficient resolution enhancement technique to extend the patterning capability of conventional lithography. The phase-separated polymers offers feature dimension and uniformity which is difficult to achieve at the resolution limit or throughput limit of lithography. As a materials-based resolution enhancement technique, DSA has been used to augment the patterning capability of conventional lithography. Recently, DSA has been transitioned from experiments in the research labs to the feasibility evaluation at various pilot lines. Many DSA schemes such as frequency multiplications and pattern rectification have been demonstrated on 300mm wafers and can be further integrated into low-cost, high-volume manufacturing process.

In this paper, we will discuss the DSA materials, DSA processes, and integration of DSA into standard lithography as well as the extendibility of DSA. To achieve good DSA performance, co-optimization of DSA materials, processes and directing prepatterns is required. Desired DSA patterns can be generated using well-designed directing prepatterns based on DSA model and design rules. Examples for complex and designable DSA patterns and extension into sub-10nm half-pitch DSA will be demonstrated.

9083-74, Session 15

The era of nanomedicine: perspectives and potential applications in oncology *(Keynote Presentation)*

Samuel Achilefu, Washington Univ. School of Medicine in St. Louis (United States)

Nanomedicine is a branch of nanotechnology that deals with the use of nano-sized materials and systems for biosensing, monitoring, diagnosing, and treating diseases. Nanotechnology facilitates the development of miniature medical devices with improved reporting and treatment capabilities, seamless integration in surgical suites with minimal interference, and potential to fully achieve the promise of individualized medicine. A unique feature of these materials is the ability to incorporate multidimensional imaging and treatment strategies into nanomaterials. Depending on the intended application, the nanomaterials could be administered topically or intravenously and non-invasive or minimally invasive procedures could be used to monitor the treatment response. Paradigm-shifting areas of nanomedicine in oncology include the development of highly sensitive and multifunctional diagnostic kits, biomarker-targeted therapies, multimodal reporting strategies, in vivo biosensors and monitoring devices, and controlled drug release approaches. An overview of these aspects of nanomedicine in cancer imaging and treatment will be reviewed, including the challenges of using nanomedicine in clinical settings.

9083-75, Session 15

Clinically-translated ultra-small silica nanoparticles for cancer-targeted imaging *(Invited Paper)*

Michelle S. Bradbury, Pat B. Zanzonico, Snehal Patel, Richard Carvajal, Steven M. Larson, Memorial Sloan-Kettering Cancer Ctr. (United States); Ulrich B. Wiesner, Cornell Univ. (United States)

Despite recent advances in imaging probe development for biomedicine, the translation of targeted diagnostic platforms remains challenging. Nanomaterials platforms currently under evaluation in oncology clinical trials are largely non-targeted drug delivery vehicles or devices to thermally treat tissue; these are not typically surface-modified for direct detection by clinical imaging tools. New tumor-selective platforms need to satisfy critical safety benchmarks, in addition to assaying targeted interactions with the microenvironment and their effects on biological systems. Metabolic imaging, such as positron emission tomography, and post-processing analysis tools, are essential for providing quantitatively accurate data of whole-body distributions, targeting kinetics, and clearance profiles of new agents transitioning into early-phase clinical trials. The application of these methods to a new class of renally-cleared, fluorescent inorganic (silica) particle probes, Cornell dots (C dots), surface-modified with radioiodine and integrin-binding ligands, has led to a clinically-translatable product for cancer detection, staging, and targeted therapeutics. A first-in-human PET study showed no adverse events in melanoma subjects. Pharmacokinetic behavior and mean organ absorbed doses were comparable to those found for other commonly used diagnostic radiotracers. Average effective absorbed doses in human subjects were equivalent to those measured in our preclinical melanoma models. Particles demonstrated bulk renal clearance; no appreciable whole-body activity was seen by 72-hour post-injection. Further, by exploiting the enhanced photophysical properties of the encapsulated dye, this dual-modality platform has enabled real-time optical imaging of lymphatic drainage patterns when injected locally about the tumor site, which can improve visualization of the surgical field and simplify SLN mapping procedures for surgeons. Sentinel lymph nodes have been localized in spontaneous melanoma miniswine models using an intraoperative handheld fluorescence camera system, with pre-operative PET and histologic correlation. Using these state-of-the art technologies, improved detection sensitivity and discrimination of metastatic tumor burden within PET-positive neck nodes was found relative to standard-of-care tracers for cancer staging. The possibility of visualizing nodal disease spread and tumor extent in relation to critical structures, while performing extended real-time intraoperative mapping procedures, has important implications for disease staging, prognosis, and treatment planning.

9083-76, Session 15

Bimodal imaging probes: design and applications *(Invited Paper)*

Peter Caravan, Massachusetts General Hospital (United States)

Bimodal imaging probes are molecules that contain two reporter functions that make the molecule detectable using two distinct imaging modalities, e.g. PET and MRI. While it may be synthetically feasible to incorporate different imaging reporters, the application of a bimodal probe is not necessarily apparent. For instance, what is the benefit of using a bimodal probe versus using two modality specific probes? This is especially true for small molecules where incorporation of a second imaging reporter moiety may alter the affinity of the probe for its target and may lead to unfavorable pharmacokinetics. Here we describe our work in synthesizing bimodal probes that maintain their intended biological properties. We also describe probes and applications where having a bimodal probe is key to answering a specific biological question.

9083-77, Session 15

Quantitative simultaneous PET-MR imaging *(Invited Paper)*

Georges El Fakhri, Massachusetts General Hospital (United States)

Simultaneous PET-MR is a novel and promising imaging modality that is generating substantial interest in the medical imaging community, while offering many challenges and opportunities. Unlike sequentially-acquired WB PET-CT scans, the simultaneous acquisition of MR and PET data can be used to incorporate tagged MR motion information and anatomical MR priors within the PET reconstruction mode as well as combining physiological information from PET and MR measurements. In this talk, we present a framework for simultaneous PET-MR and present several examples in oncology and neuroscience where simultaneous PET-MR has great potential for dramatically improving diagnostic accuracy.

9083-78, Session 15

Translational molecular imaging in oncology *(Invited Paper)*

Sridhar Nimmagadda, Johns Hopkins Univ. (United States)

Molecular imaging allows for the non-invasive detection and monitoring of malignant phenotypes using specific probes, methods and modalities at high resolution. Over the last decade, targeted therapeutics have significantly altered patient stratification and treatment, resulting in improved survival rates and therapeutic outcomes. Paradoxically, clinical imaging agents used for diagnosing, staging and more importantly monitoring targeted therapies are currently based on metabolism, which are not ideal for certain cancers. The lack of targeted imaging agents is more apparent in the management of a number of cancers such as breast, prostate and small cell lung cancers (SCLC). Identification, development and clinical translation of targeted imaging agents for prostate cancer and SCLC, including multimodality agents, will be discussed.

9083-79, Session 15

18F-PET/fluorescent multimodality imaging and an 18F-analogue to the 99mTc generator for solid-phase 18F-PET/fluorescent antibody generation *(Invited Paper)*

Richard Ting, Univ. of California, San Diego (United States)

PET and NIRF are two of our most sensitive imaging modalities. They are useful in tracer quantities and, in a multimodality imaging combination, they are highly synergistic. We demonstrate this using tilmanocept, a radio-pharmaceutical that very recently cleared phase III clinical trials as a [99mTc] SPECT agent. When labeled as a [18F]-PET/NIRF analogue, we show that tilmanocept can be imaged at superior resolution in all its facets: depth penetration, magnification, and temporal resolution. Having demonstrated the superior potential of this PET/NIRF multimodality imaging combination over stand-alone PET, NIRF, or SPECT imaging modalities, we were emboldened to apply some advanced synthetic chemistry to construct a solid-phase system for generating PET/NIRF labeled compounds. The new system is analogous to the [99Mo/99mTc] SPECT generator used to generate our most clinically utilized radiotracer, [99mTc]-sestamibi. We apply this advanced technology to label an equally advanced target: the full length anti-EpCAM antibody. Using an aqueous [18F]-sodium fluoride we simultaneously [18F]-fluoride label our antibodies and trigger their solid-phase release. We demonstrate that the generated [18F]-PET/NIRF antibody retains its antigen specific affinity and antigen specific endocytosis. This system promises to be competitive with 68Ga generators, and we expect that the solid-phase PET/NIRF labeling technology described here can be extrapolated to most other antibodies and all other classes of molecules that are chemically more stable including peptides, proteins, oligonucleotides, and especially, small molecules.

9083-80, Session 15

Ultrasound-switchable fluorescence at near-infrared wavelength for deep-tissue high-resolution imaging *(Invited Paper)*

Baohong Yuan, Mingyuan Wei, Yanbo Pei, Yuan Liu, Zhiwei Xie, Bingbing Cheng, Kytai T. Nguyen, The Univ. of Texas at Arlington (United States)

Ultrasound-switchable fluorescence (USF) imaging has been recently demonstrated for high-resolution deep-tissue fluorescence imaging. The promising results of the USF technique highly rely on excellent and unique USF contrast agents. For in vivo applications, red or near infrared (NIR) USF contrast agents are needed for avoiding significant tissue absorption and autofluorescence. We herein report NIR-dye-encapsulated poly (N-isopropylacrylamide) nanoparticles (PNIPAM NPs) and demonstrate their feasibility of high resolution USF imaging in deep tissue. To quantitatively compare the performance among different contrast agents, five primary parameters are defined, which include 1) peak excitation and emission wavelengths; 2) fluorescence intensity on-to-off ratio; 3) the fluorescence lifetime of the switch-on fluorophore and fluorescence lifetime on-to-off ratio; 4) threshold to switch on fluorescence; and 5) off-to-on transition bandwidth. Based on these parameters, we found that indocyanine green (ICG) encapsulated NPs have NIR excitation and emission peaks, a large intensity switching ratio, a narrow switching transition bandwidth, and an adjustable temperature switching threshold. These properties make them very promising agents for future in vivo USF imaging work. The USF image results show that these NPs can be used for high-resolution deep-tissue imaging.

9083-81, Session 16

NASA ESTO's strategic investments in space-based radiometer technology and flight validation *(Keynote Presentation)*

Charles D. Norton, Jet Propulsion Lab. (United States)

NASA's Earth Science Technology Office (ESTO) performs strategic investments in instrument subsystems, information systems, and most recently CubeSats platforms to raise the technology readiness level (TRL) of relevant Earth Science Decadal Survey technologies to reduce and retire risk before infusion into flight missions. Since 1998, ESTO has made numerous investments spanning all aspects of radiometer development from hardware components and instrument subsystems that have been developed and tested in both the laboratory and airborne environment, to related modeling, data processing, and analysis technologies that impact the products that can be produced in atmospheric science. Nevertheless, with the growing interest in using CubeSats as platforms for rapid access to space, radiometers have been identified as a compelling technology to initiate new approaches to spaceborne observations in the microwave spectrum. In particular, due to their inherent size, weight, and power many new observation concepts have been proposed to fly radiometers in space using CubeSats, both as stand alone platforms, and constellations, to usher in new techniques to advance weather and climate science. In this talk, we will introduce the ESTO office, our programmatic strategy and approach to strategic investment in Earth science technologies, our history specifically in the area of space-based radiometer technology development, and our current approach to validating these systems using CubeSats as a platform for technology maturation.

9083-82, Session 16

The power of inexpensive satellite constellations *(Invited Paper)*

Lars P. Dyrud, Draper Lab. (United States)

Two thematic drivers are motivating the science community towards constellations of small satellites, the revelation that many next generation system science questions are uniquely addressed with sufficient numbers of simultaneous space based measurements, and the realization that space is historically expensive, and in an environment of constrained costs, we must innovate to "do more with less". We present analysis that answers many of the key questions surrounding constellations of scientific satellites, including research that resulted from the GEOScan community based effort originally intended as hosted payloads on Iridium NEXT. We present analysis that answers the question how many satellites does global system science require? Perhaps serendipitously, the analyses show that many of the key science questions independently converge towards similar results, i.e. that approximately 60+ satellites are needed for transformative, as opposed to incremental capability in system science. The current challenge is how to effectively transition products from design to mass production for space based instruments and vehicles. Ideally, the lesson learned from past designs and builds of various space products should pave the way toward a better manufacturing plan that utilizes just a fraction of the prototype's cost. Using the electronics industry implementations of mass customization as an example, we will discuss about the benefits of standardization in design requirements for space instruments and vehicles. For example, the instruments (payloads) are designed to have standardized elements, components, or modules that interchangeably work together within a linkage system. Following the 80/20 rule, identification of cost distribution early on and application of learning curve will be critical for keeping manufacturing cost . These findings combined with designing manufacturability into the product, setting up intelligent integration and test plan, application of spiral development and feedback loops, and application of heuristics to determine test feasibility versus cost benefit, will guide the efforts in reducing the cost of manufacturing multiple space based products. We conclude with a discussion on implementation plans and the new paradigms for community and international cooperation enabled by small satellite constellations.

9083-83, Session 16

RAVAN: A pathfinder for accurate Earth radiation budget measurements *(Invited Paper)*

Dong L. Wu, Warren J. Wiscombe, NASA Goddard Space Flight Ctr. (United States); William H. Swartz, Johns Hopkins Univ. Applied Physics Lab. (United States); Lars P. Dyrud, Draper Lab. (United States); Steven R. Lorentz, L-1 Standards and Technology, Inc. (United States); Stergios J. Papadakis, Johns Hopkins Univ. Applied Physics Lab. (United States)

A constellation in low Earth orbit can overcome the limited sampling that is the hallmark challenge of all current Earth Radiation Budget (ERB) measurements. Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) is a CubeSat mission, funded by NASA's Earth Science Technology Office (ESTO), to pioneer a new way for solving the ERB problem with compact and low cost radiometers on distributed low-Earth-orbit platforms. The RAVAN concept is a space version of the Argo ocean-buoy array that fundamentally changed our view of ocean heat content. The Earth radiation imbalance (ERI), the difference between incoming and outgoing radiation at the top of the atmosphere, is the single most important number for predicting the course of climate change over the next century. If ERI is negative, global warming will slow down and eventually reverse. If ERI is 2 W/m2, global warming will accelerate since this dumps a huge amount of extra heat into the Earth system. There is strong evidence that ERI is positive, ranging between 0.1 and 0.9 W/m2. Yet, the current ERB measurements from space are not accurate enough to determine ERI. They are tuned to agree with climate model calculations and ocean heat content observations. To a large extent, this inaccuracy is due to poor temporal coverage and insufficient treatment of anisotropic radiation. The conventional ERB observing concept has reached a technological asymptote and requires massive injections of money for small incremental improvement. A new approach for ERB observation is needed. The primary goal of RAVAN is to measure the outgoing radiation flux to an accuracy of 0.3 W/m2, which is sufficient to quantitatively evaluate the course of future climate change once a RAVAN constellation is implemented.

9083-84, Session 16

High-accuracy radiometer and calibrator design for an ESTO CubeSat Mission: RAVAN *(Invited Paper)*

Steven R. Lorentz, Allan W. Smith, L-1 Standards and Technology, Inc. (United States); William H. Swartz, Johns Hopkins Univ. Applied Physics Lab. (United States); Lars P. Dyrud, Draper Lab. (United States); Warren J. Wiscombe, Dong L. Wu, NASA Goddard Space Flight Ctr. (United States); Stergios J. Papadakis, Johns Hopkins Univ. Applied Physics Lab. (United States)

A new approach is being pursued to address the critical question of the global energy balance of the Earth. NASA's Earth Science Technology Office (ESTO) recently funded a mission to demonstrate technologies needed to improve measurements of the Earth's global outgoing radiation. The objective of the Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) mission is to demonstrate a compact, low cost radiometer with an absolute uncertainty sufficiently small to resolve the Earth radiation imbalance (ERI) between incoming and outgoing radiation.

This mission will serve as the initial proof-of-technology demonstration that will lead to the development of a radiometer constellation distributed in low earth orbit to collectively provide near simultaneous global measurement of the ERI. The earth radiation budget can vary largely in a time scale between a few hours and 1 month, thereby providing a data set that will enable studies of short time scale dynamical processes as well as uncertainty reduction in the monthly mean.

The radiometer suite is composed of four wide-field-of -view bolometric detectors. The absorbing element in one pair is based on a thinned silicon wafer coated with vertically aligned carbon nanotubes (VACNT) and second pair consists of cavity based detectors. Each pair is composed of a total (broadband) channel and a shortwave channel to differentiate between solar reflected energy and thermally emitted long wave energy. A sapphire domed filter is used in the shortwave channel to define a 0.2 μm to 5 μm pass band. The radiometer suite is housed in a 1-U CubeSat volume.

9083-85, Session 16

Carbon nanotubes as a photon filter for energetic particle detectors *(Invited Paper)*

David M. Deglau, Donald G. Mitchell, Andrew H. Monica, G. Bruce Andrews, John E. Mattson, Stergios J. Papadakis, Johns Hopkins Univ. Applied Physics Lab. (United States)

Detecting energetic particles is a useful approach in studying space plasmas. Of specific interest are energetic neutral atoms (ENA) because their trajectories are unaffected by electric or magnetic fields. Imaging the ENA flux allows for the mapping of remote plasmas. In order to detect such particles, solid-state detectors are advantageous due to their lightweight and low power. However in the sensing environment the photon flux is usually several orders of magnitude higher than the ENA flux. Thus, in order to detect the energetic particles the photon flux must be blocked. Therefore, thin metal or carbon film filters that allow the transmission of ENAs while attenuating the photon signal are used. Our goal was to improve the performance of these filters by using carbon nanotubes (CNTs) a filter medium due to their low density and highly effective light absorption attributes. For a given mass per unit area (the parameter which sets the particle transmission energy threshold), CNTs are expected to absorb photons significantly better. The CNTs were grown by a water assisted chemical vapor deposition technique and pulled from their substrate to generate a CNT sheet covering an aperture. In order to test the performance of the CNT sheet as a filter, the transmissions of light and alpha particles were measured. We were able to achieve filter performance that resulted in alpha particle attenuation of 5 keV with an optical density of 3.12x10-1.

9083-86, Session 17

Terahertz electronics for sensing applications *(Keynote Presentation)*

Michael S. Shur, Rensselaer Polytechnic Institute (United States)

Terahertz sensing is enabling technology for detection of biological and chemical hazardous agents, cancer detection, detection of mines and explosives, providing security in buildings, airports, and other public space, short-range covert communications (in THz and sub-THz windows), and applications in radioastronomy and space research. I will review the-state-of-the-art of existing THz sources, detectors, and sensing systems and prospects for novel emerging devices enabling terahertz electronics for sensing applications. Two-terminal semiconductor devices are capable of operating at the low bound of the THz range, with the frequencies up to a few terahertz achieved using Schottky diode frequency multipliers. High-speed three terminal electronic devices (FETs and HBTs) are approaching the THz range (with cutoff frequencies and maximum frequencies of operation above 1 THz and close to 0.5 GHz for InGaAs and Si technologies, respectively). sA new approach called plasma wave electronics recently demonstrated terahertz emission and detection in GaAs-based and GaN-based HEMTs and in Si MOS and SOI, including the resonant THz detection. Graphene and 2D materials "beyond graphene" have also emerged as candidates for plasmonic THz detectors, modulators, and emitters. THz radiation couples to a field effect transistor via contact pads and/or bonding wires (even in the absence of any antenna structures) and induces voltages at the THz radiation frequency between the gate and source and the gate and drain. These THz voltages launch plasma waves propagating into the channel. In a collision-dominated regime, the channel acts as lossy capacitive-resistive transmission line, and the plasma wave decays propagating into the channel. At high intensities of THz radiation, plasma shock waves (i.e. shock waves of the electron density) propagate in the FET channels. Using synchronized THz plasmonic transistor arrays instead of single devices is predicted to improve performance by several orders of magnitude.

9083-87, Session 17

Analysis of sub-THz atmospheric data from transmissometer and radar sensors *(Invited Paper)*

Lawrence Scally, Jason Fritz, Colorado Engineering, Inc. (United States); Albin J. Gasiewski, Univ. of Colorado at Boulder (United States)

Colorado Engineering, Inc. (CEI) and the University of Colorado, Boulder (CU) are collaborating on two projects to investigate active sensor systems at ~100 to 1000 GHz. The overall goal of the Terahertz Atmospheric and Ionospheric Propagation, Absorption and Scattering (TAIPAS) project is to develop a model relevant for atmospheric propagation and remote sensing in the range of ~1-3000 GHz, along with designing and developing a THz propagation range suitable for evaluation of several critical aspects of THz propagation that have heretofore never been studied in the field. Specifically, TAIPAS focuses on: 1) the design of a baseline 325-340 GHz phase-coherent transmissometer to extend the measurements performed during the 1983 Flatville (100-300 GHz) field studies to higher frequencies (~300-1000 GHz) in open path conditions, and 2) the integration and validation of existing propagation models for absorption, refraction, and beam scintillation into a common modeling framework useful for image generation and link analysis from ~1 to 1000 GHz. The transmitter is being located on the CU Center for Environmental Technology (CET) rooftop observatory on the main Boulder campus. Two phase coherent receivers, spaced up to ~8 m apart enable measurement of the mutual coherence function. These receivers are located at the NIST/NTIA Green Mesa site approximately 1.78 km from the transmitter along a nearly level path. Timing for coherency is achieved through a line-of-site C-band radar link. Initial results of the TAIPAS experiment will be presented.

In addition, a second CEI/CU project focusses on the development and demonstration of an imaging radar operating in the 205-220 GHz transmission window. This system uses dual receivers spaced about 10-20 cm apart in height to provide surface topography estimation using interferometry by measuring the phase difference between the two receivers. Given the short wavelength and baseline, theory suggests that there will be enough coherence for quality height map estimation. Data from initial experiments will be presented focusing on the phase of the reflected signals at ranges of tens of meters.

9083-88, Session 17

mmW staring focal plane arrays for security applications *(Invited Paper)*

Michael A. Gritz, Leonard P. Chen, Borys Kolasa, Robert Burkholder, Sean F. Harris, Raytheon Co. (United States); Brian A. Lail, Florida Institute of Technology (United States)

Millimeter-wave (mmW)/sub-mmW/THz region of the electro-magnetic spectrum enables imaging thru clothing and other obscurants such as fog, clouds, smoke, sand, and dust. Therefore considerable interest exists in developing low-cost passive millimeter-wave imaging (PMMWI) systems. Previous PMMWI systems have evolved from crude mechanically scanned,

single element receiver systems into very complex multiple receiver camera systems. Initial systems required many expensive mmW integrated-circuit low-noise amplifiers. In order to reduce the cost and complexity of the existing systems, attempts have been made to develop new mmW imaging sensors employing direct detection arrays. In this presentation, we report on Raytheon's recent development of a unique focal plane array technology, which operates broadly from the mmW through the sub-mmW/THz region. Raytheon's innovative nano-antenna based detector enables low-cost production of 2D staring mmW focal plane arrays (mmW FPA), which not only have equivalent sensitivity and performance to existing PMMWI systems, but require no mechanical scanning. We also present recently generated images of objects obscured under clothing using our 2D mmW staring FPA.

9083-89, Session 18

Case study of concealed weapons detection at stand-off distances using a compact, large field-of-view THz camera *(Invited Paper)*

Linda Marchese, Marc Terroux, Denis G. Dufour, Martin Bolduc, Claude Chevalier, Francis Genereux, Hubert Jerominek, Alain Bergeron, INO (Canada)

The detection of concealed weapons in crowd situations is a critical need and solutions are being sought after by security agencies at the federal, state and municipal levels. Millimeter waves have been evaluated for these kinds of applications, but the currently available technologies are typically too large and bulky to allow for widespread deployment. Alternatively soft X-rays have been considered but safety issues hinder their acceptance.

Terahertz technology is ideally suited for such an application as it has the ability to see through clothing, and offers higher resolution than in the millimeter band, also being more compact. THz photons have lower energy than infrared and do not show the ionizing properties of X-ray radiations. The longer Terahertz waves penetrate deeper into various materials then their visible and infrared counterparts. Though the wavelength is longer it has been shown that high resolution in a small form factor can be obtained in the THz wavebands thanks to the use of small pixel pitch detectors.

In this paper, a case study for the use of a compact THz camera for active see-through imaging at standoff distances is presented. More specifically, the case of seeing through clothing is analyzed in the perspective of concealed weapons detection. The paper starts with a review of the characteristics of a high resolution THz camera exhibiting small subwavelength pixel size and large field-of-view. Some laboratory results of concealed object imaging along with details of a concept for live surveillance using a compact see-through imaging system are reviewed.

9083-90, Session 19

Re-engineering defense and homeland security applications using MWIR and LWIR QCLs *(Keynote Presentation)*

C. Kumar N. Patel, Pranalytica, Inc. (United States)

Quantum cascade lasers are revolutionizing the defense and homeland security applications because these are the only primary lasers, converting electrical power directly into laser radiation, that provide continuous wave laser radiation at room temperature in the 3.5 μm to >12 μm region. QCLs are rapidly displacing other sources of radiation in these spectral regions, including OPO's, optically pumped semiconductor lasers and low power CO2 lasers. Applications that are being revolutionized include infrared counter measures to protect aircraft from MANPADS, MWIR/LWIR target illuminators/designators, IFF beacons, and in-situ and stand-off sensors for the detection of chemical warfare agents and explosives.

In this Keynote Paper, I will review the advances in QCL technology as well as applications.

9083-91, Session 19

Ultrafast laser bleaching technique for stand-off characterization and augmentation *(Invited Paper)*

Inna Zakharova, Univ. of Alberta (Canada) and Volyn State Univ. (Ukraine)

Photonic bleaching is a common effect that has been used in laser Q-switch techniques for years. Bleaching may occur when continuum of valence band electrons with energies available for transition is depleted to the level when absorption and photon energy transitions practically stops and material becomes transparent for a period of time. That period of time of material transparency is not equal to electron excitation time: quite opposite, when excitation lasts femtoseconds, the opposite process-relaxation, that eventually returns the material back in its original non-transparent state may last much longer. At the time of relaxation the material stays transparent for specific spectral band radiation. Due to the changes in material electronic and optical structures the magnetic structure of material is changing as well leading to complete temporal transition of the material physical properties. The more complex is material electronic structure the longer relaxation process is lasting. It may last from nano-seconds up to micro-seconds in commonly used semiconductors, and up to milliseconds – in complex organic molecules. It may have two obvious applications: one in continues remote manipulations of material properties, another in standoff characterization that takes into account relaxation time that is specific for material of interest. Paper is focused at the specifics of ultra-fast lasers that allows in bleaching applications to extend light-induced material properties and as well as at power balance analysis that allows using ultrafast-lasers for standoff characterization, remote control and material properties manipulations.

9083-92, Session 19

Approaches to generation of tunable mid-IR ultrafast pulses with fiber sources *(Invited Paper)*

Igor Pastirk, TOPTICA Photonics Inc. (United States); Andreas Brodschelm, Alexander Sell, TOPTICA Photonics AG (Germany)

Mid- infrared ultrafast pulses are of interest in different applications ranging from vibrational spectroscopy, strong field physics (stable CEP) to detection of trace quantities of compounds. Traditional approach using solid state lasers is mature but sensitive technology that is restricted to laboratory use due to its complexity. In real-world applications, ultrashort fiber lasers offer a more rugged, portable and scalable platform for the generation of tunable, brilliant mid-IR femtosecond pulses. This paper will cover several recent approaches to generation of high spectral intensity femtosecond pulses in MID-IR region including DFG, OPO and OPCPA.

9083-93, Session 20

Ultrafast fiber lasers: practical applications *(Invited Paper)*

Igor Pastirk, TOPTICA Photonics Inc. (United States)

Over past three decades ultrafast lasers have come a long way from the bulky, demanding and very sensitive scientific research projects to widely available commercial products. For the majority of this period the titanium-sapphire-based ultrafast systems were the workhorse for scientific and emerging industrial and biomedical applications. However the complexity and intrinsic bulkiness of solid state lasers have prevented even larger penetration into wider array of practical applications. With emergence of femtosecond fiber lasers, based primarily on Er-doped and Yb-doped fibers that provide compact, inexpensive and dependable fs and ps pulses, new practical applications have become a reality. The overview of current state of the art ultrafast fiber sources, their basic principles and most prominent applications will be presented, including micromachining and biomedical implementations (ophthalmology) on one end of the pulse energy spectrum and 3D lithography and THz applications on the other. Due to scalability and new dopants like thulium, big potential lies in MID-IR region that opens possibilities in sensing, and spectroscopy applications. With development of new PCF fibers the high power ultrafast laser are new available. Current state of the technology allows man-portable systems of mid-range powers suitable for field use.

9083-94, Session 20

Standoff laser photoacoustic spectroscopic-based sensor for remote sensing *(Invited Paper)*

Ramesh C. Sharma, Anil K. Maini, Laser Science and Technology Ctr. (India)

An active spectral sensor for chlorophyll detection based on quartz crystal tuning fork detector. The sensors use modulated diode laser radiations that can be differentiated from ambient background radia- tions by the detector. Experimentally, electrical and optical parameters of quartz crystal tuning fork detec-tor (QCTF) were studied. Quartz Enhanced Laser Photoacoustic signal of chlorophyll traces dissolved in water and adsorbed on surfaces, using 532 nm and 635 nm wavelength lasers from a standoff distance of up to 25 m. With the availability of high-power tunable diode laser, the technique offers a wide range of applicability for point and standoff sensing. Standoff Quartz Enhanced Laser Photoacoustic Spectroscopy(QE-LPAS) technique is emerging as a Powerful technique for detection of hazardous chemicals,. Experimen-tally, recorded standoff photoacoustic spectrum of hazardous molecules adsorbed at diffused Surfaces from a distance of upto 20m.Tunable mid infrared quantum cascade lasers(MIR-QCL)in the wavelength range 7.0-12.0 micron are being used as optical source. Samples of Dinitrotoluene(DNT), were Penta erythritol tetra nitrate (PETN) having adsorbed concentration of approximately 5.0microgram g/cm detected. Acetone and nitrobenzene sample sinliquid having concentration 200nl approximately sealed in polythene sachet were detected from a standoff distance of upto 20m.

9083-95, Session 20

A mobile platform for infrared photothermal imaging of trace explosives *(Invited Paper)*

Christopher A. Kendziora, Robert Furstenberg, Michael R. Papantonakis, Viet Nguyen, Jeff M. Byers, R. Andrew McGill, U.S. Naval Research Lab. (United States)

We are developing a technique for the stand-off detection of trace explosives on relevant substrate surfaces using photo-thermal infrared (IR) imaging spectroscopy (PT-IRIS). This approach leverages one or more micro-fabricated IR quantum cascade lasers, tuned to strong absorption bands in the analytes and directed to illuminate an area on a surface of interest. An IR focal plane array is used to image the surface thermal emission upon laser illumination. The PT-IRIS signal is processed as a hyperspectral image cube comprised of spatial, spectral and temporal dimensions as vectors within a detection algorithm. Increased sensitivity to explosives and selectivity between different analyte types is achieved by narrow bandpass IR filters in the collection path. We have demonstrated 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. This talk will include an overview of the approach and recent experimental results using a cart-based mobile platform to detect explosives and possible interferents on relevant substrates including metal, plastic, glass and painted car panels.

References: R. Furstenberg et al. Applied Physics Letters 93, 224103 (2008), C. A. Kendziora et al.; Proc. of SPIE Vol. 8373 83732H-1 (2012). C. Kendziora et al.; Proc. of SPIE Vol. 8709, 87090O-1 (2013); R. A. McGill et al.; US Patent #8,101,915 B2 (2012). This research is sponsored by ONR/NRL and the U.S. Army Night Vision & Electronic Sensors Directorate.

9083-96, Session 20

Point and standoff detection of trace explosives using quantum cascade lasers *(Invited Paper)*

Seonghwan Kim, Univ. of Calgary (Canada); Dongkyu Lee, Xunchen Liu, Charles W. Van Neste, Thomas G. Thundat, Univ. of Alberta (Canada)

Chemical sensors based on micro/nanoelectromechanical systems (MEMS/NEMS) offer many advantages. However, obtaining chemical selectivity in MEMS/NEMS sensors using chemoselective interfaces has been a longstanding challenge. Despite their many advantages, MEMS/NEMS devices relying on chemoselective interfaces do not have sufficient chemical selectivity. Therefore, highly sensitive and selective detection and quantification of chemical molecules using real-time, miniature sensor platforms still remains as a crucial challenge. Incorporating photothermal/photoacoustic spectroscopic techniques with MEMS/NEMS using quantum cascade lasers can provide the chemical selectivity without sacrificing the sensitivity of the miniaturized sensing system. Point sensing is defined as sensing that require collection and delivery of the target molecules to the sensor or sensor surface for detection and analysis. For example, photothermal cantilever deflection spectroscopy, which combines the high thermal sensitivity of a bimetallic microcantilever with high selectivity of the mid infrared (IR) spectroscopy, is capable of obtaining molecular signatures of extremely small quantities of adsorbed explosive molecules. On the other hand, standoff sensing is defined as sensing where the sensor and the operator are at distance from the target samples. Therefore, the standoff sensing is a non-contact method of obtaining molecular signatures without sample collection or processing. The distance of detection depends on the power of IR source, the albedo of the targeted surface, the sensitivity of a detector, and the efficiency of the collecting optics. By employing broadly tunable, high power quantum cascade lasers and a boxcar averager, molecular recognition of trace explosive compounds on real-world surfaces has been achieved at a distance of five meters.

9083-97, Session 20

Recent advances in quantum cascade external cavity laser systems for sensing applications
(Invited Paper)

Leigh J. Bromley, David B. Arnone, David B. Caffey, William B. Chapman, Sam Crivello, Timothy Day, Allen Priest, Michael Pushkarsky, Daylight Solutions Inc. (United States); Charles C. Harb, The Univ. of New South Wales (Australia)

Mid-infrared laser spectroscopy is highly promising for a variety of sensing applications, given the presence of strong molecular absorption features—and atmospheric transmission windows—in the well-known mid-IR spectral 'fingerprint' region. Further, the high brightness, narrow linewidth and broad tuning ranges of which External Cavity quantum cascade lasers (ECqcLs™) are capable make them ideally suited to meeting sensing requirements for: high chemical sensitivity and specificity; identifying a range of substances unambiguously with one instrument, and practical standoff distance. Commercial ECqcLs have also demonstrated that these platforms can provide the ruggedness, compact size, efficiency and turn-key operation for deployable sensing systems.

In this paper we survey recent advances in ECqcLs. We report recent advances in broadly tunable ECqcL systems, including tuning ranges of >300 cm-1 for single-ECqcL CW devices and >800 cm-1 for a novel multi-ECqcL device. By way of contrast, we also discuss recent advances in robust mode-hop-free, narrow linewidth performance from a commercial ECqcL-based system. Typical performance data showing linewidths of <5 MHz, low noise, and phase-continuous tuning ranges >50 cm-1 will be presented. We also discuss sensing applications that benefit from these advances in mid-IR laser source capabilities. These include recent advancements in the development of real-time cavity ringdown spectroscopy (CRDS) over a wide bandwidth using quantum cascade laser systems, with the goal of making headspace measurements of molecules at trace levels. We report results of two systems ideally suited to making headspace measurements of molecules at trace levels that measure nitromethane, acetonitrile, acetone, and nitroglycerin, where the spectra containing at least 150,000 spectral data points are obtained in less than four seconds.

9084-1, Session 1

Neurobiomimetic constructs for intelligent unmanned systems and robotics

Jerome J. Braun, Danelle C. Shah, Marianne A. DeAngelus, MIT Lincoln Lab. (United States)

Decision-making is of paramount importance for robots, unmanned systems and autonomous systems. Such machines must perceive and interpret available information and make correct decisions despite incomplete sensor data, uncertainties, dynamics of the situation, and various unexpected conditions or events, in order to deal with the complexity of typical real-life situations. When the problem, including the task and its application, is sufficiently constrained, current algorithmic paradigms can perform very well. However, in real-life situations the expected constraints, and deviations from what is conceivably expected a priori, are frequently exceeded. Such situations challenge the current algorithmic paradigms, including even the state-of-the-art machine-learning and machine-reasoning approaches. In contrast, various biological species exhibit remarkable robustness in terms of decision-making, adaptability and resourcefulness.

This paper discusses a paradigm we refer to as 'neurobiomimetic', which involves emulations of brain neuroanatomy and neurobiology aspects and processes. Neurobiomimetic constructs include rudimentary and down-scaled computational representations of brain regions, sub-regions, and synaptic connectivity. Many different instances of neurobiomimetic constructs are possible, depending on various aspects such as the initial conditions of synaptic connectivity, number of neuron elements in regions, connectivity specifics, and more, and we refer to these instances as 'animats'. The animats implemented in this work, contain over 47,000 neuron elements and over 720,000 synaptic connections.

Implementing such large and complicated structures poses an overwhelming developmental challenge. To address that challenge, in the initial part of our neurobiomimetic effort we developed an enabling technology we refer to as Neurobiomimetic Cognitive Architecture Foundation Framework (NCAFF), which encapsulates complex details that underlie aspects such as representation of neuroanatomical structures and synaptic connectivity patterns. That part of our neurobiomimetic work also included an initial implementation of animat, construction of a virtual-reality environment for computational experiments and studies, and initial animat experiments. The cognitive task setting has been spatial memory and learning.

This paper focuses largely on the more recent part of our neurobiomimetic effort which, beyond NCAFF improvements, was concentrated primarily on significant enhancements to and experiments with the animats. Those enhancements, extensions, and experiments spanned several interrelated areas, including achieving stability and oscillatory patterns of neural activity, and a number of learning modes motivated by effects that occur in biological brains, specifically those akin to memory replay, learning by demonstration and operant conditioning. We conducted experiments and efficacy studies across learning modes in the context of spatial learning and navigation by landmarks, in a virtual-reality environment. The results of these experiments indicate learning for self-development of spatial awareness.

More broadly, computational mimicking of mechanisms of biological brains such as the effort discussed in this work are particularly promising for intelligent unmanned systems and robotics. Spanning the domains of computer science, cognitive science and neuroscience, they can lead to artificial cognition and enable unmanned systems with multi-functionality and adaptability closer to those seen in biological species.

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9084-2, Session 1

Intermittent communications modeling and simulation for autonomous unmanned maritime vehicles using an integrated APM and FSMC framework

Ayodeji Coker, Logan Straatemeier, SPAWARSYSCEN Pacific: San Diego (United States); Kelly Griendling, Pierre Valdez, Georgia Institute of Technology (United States); Ted Rogers, SPAWARSYSCEN Pacific: San Diego (United States); Daniel Cooksey, Georgia Institute of Technology (United States)

In this work a framework is presented for addressing the issue of intermittent communications faced by autonomous unmanned maritime vehicles operating at sea. The Adaptive Communications Framework for Unmanned Vehicles (ACF-UV) is being developed to provide predictive estimations of future states of intermittent communication links between two or more autonomous platforms as well as their respective command and control stations. The purpose of such a framework is to allow system designers, performance engineers and System of Systems designers the ability to make improved design choices that lead to better connectivity between unmanned vehicles (UxVs). Using ACF-UV mission planners will also acquire the requisite information needed for path planning and operational placement of assets to ensure optimized and sustained network connectivity.

ACF-UV, using an Advanced Propagation Model (APM), calculates maritime signal propagation loss using atmospheric and environmental conditions (temperature, humidity, pressure, etc) and phenomena (evaporation ducts) to predict signal transmission channel quality. Developed at the Space and Naval Warfare Systems Center San Diego, APM uses hybrid ray-optic and parabolic equation models to compute EM propagation over various sea and/or terrain paths, and is the only EM propagation model accredited for use in Navy systems by the Chief of Naval Operations. The propagation loss profile computed by APM represents a snap shot in time, to generate an iterative propagation loss profile, a Finite State Markov Channel (FSMC) scheme is used to model the APM-characterized physical fading channel. Based on the Gilbert-Elliot channel model, and demonstrated to be effective in the modeling of fading channels, FSMC is a probabilistic state transition model implemented in ACF-UV by partitioning the range of the received signal-to-noise ratio into a finite number of intervals, for which each state is represented as an application-defined communications channel quality [6]. The APM and FSMC models are integrated within ACF-UV to create communications awareness picture; analogous to a communication aide for each maritime UxV.

In order to assess the impact of UxV requirements and communications quality on an overall mission, a developmental simulator was also integrated into ACF-UV. Inputs for the simulation environment include: atmospheric environment characteristics (refractivity profile), radio signal specifications, UxV performance and capabilities, UxV initial locations, UxV paths and agent based behavior, and stopping criterion (time or a set goal). An Agent Based Modeling and Emergent Behavior approach is also being developed to enable UxVs to autonomously position themselves to optimize area coverage while maintaining constant communication between teams of UxVs. Outputs of the simulation are measures of performance with emphasis on the communication network which include: enemies detected, enemy radars detected, communication links lost, successful relay links, and overall mission awareness.

Also presented in this work is the approach taken to integrate these communications modeling elements with a set of mission models to implement a robust ACF-UV tool that enables users the ability to better predict and account for the impacts of intermittent communications in UxV mission planning and operations.

9084-3, Session 1

The impact of autonomy on robotic ground vehicle communications

Charles M. Shoemaker, U.S. Army Communications-Electronics Research Development and Engineering Command (United States)

No Abstract Available

9084-4, Session 1

Automating software design and configuration for a small spacecraft

Jeremy Straub, The Univ. of North Dakota (United States)

A small satellite can serve as a platform for science and engineering activities. In this role, the spacecraft's software delivers on meeting mission objectives and, to this end, it commands and controls the hardware platform. For both hardware and software, resource limitations pose a significant constraint.

In this highly constrained environment, a software expert system can serve to help spacecraft designers maximize performance without violating mission or form factor constraints. The OpenEdge system is currently being developed to do just this. OpenEdge will allow users to choose parts to integrate from a standard collection of pre-developed boards that are part of the Open Prototype for Educational NanoSats (OPEN), an effort to develop the designs and other documents required to build and test a 1-U CubeSat, or user-developed boards. It will test compatibility between the board designs and the spacecraft bus, other boards and structure. These tests will cover both electrical and mechanical compatibility.

This paper discusses an addition to this software that will assist mission software team members with the design and development of software for both core and custom-developed modules. This software will provide configuration assistance for core modules including identifying what software modules are required for each core module and providing stubs for areas where custom software must be created to perform mission specific (e.g., command) functionality. It will also provide stubs for custom developed modules and the connective code to enable integrated system operations.

This paper provides an overview of the OPEN platform, its software architecture model and the OpenEdge system. It then describes the software development and configuration augmentation for the OpenEdge system and provides a qualitative of it.

9084-5, Session 1

Modeling and simulation of an unmanned ground vehicle power system

John A. Broderick, Dawn M. Tilbury, Ella M. Atkins, Univ. of Michigan (United States)

Long-duration missions challenge ground robot systems with respect to energy storage and efficient conversion to power on demand. Ground robot systems can contain multiple power sources (e.g. fuel cell, battery, ultra capacitor). This paper presents a framework for collectively modeling the dynamics and switching between these different power components using a hybrid systems framework. The hybrid systems framework allows devices to switch on/off or between different regimes of operation, while still modeling continuous parameters such as state of charge, temperature, and power output. We apply this modeling framework to a fuel cell/battery power system that could be used on a Packbot or Talon. These models can be used to plan and optimize energy management for a ground robot during operation. We present an energy use optimization model based on timed automata, a subset of hybrid automata representing energy dynamics with linearized models to promote rapid identification of optimal energy conversion solutions for a given mission. A simulation comparison of different energy use models will be presented. Plans for experimental validation will be summarized, including hardware-in-the-loop tests using a fuel cell and a battery in combination with a programmable load bank to simulate UGV power use.

9084-6, Session 1

Mobility as a game of timing with terrain: a variant of the rocket car control problem

Paul L. Muench, David Bednarz, Amandeep Singh, Jeremy Mange, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

Traditionally, we have defined mobility by looking at a list of metrics such as: gap crossing, step obstacles, terramechanics, etc. just to name a few. These discrete metrics capture some of what we mean by mobility, but there is not a standard way to quantify the relative value of one metric vs. the other. Also, these metrics are based on how wide wheel-based vehicles perform, and they do not capture the novel capabilities of, say, a legged robot, which is designed for load carriage through narrow passageways and mountainous trails. Rather than enumerating an even longer list of metrics to capture these novel capabilities, we seek a general framework for mobility which compares the relative value of legged, wheeled, and tracked mobility.

We seek to model the interaction between a vehicle and its operating environment as a strategic game between two players. In this paper, we will describe the mobility of a rocket car under resistance from the terrain as a zero sum differential game between the mobility player and the terrain player. We will bound the force that each player is able to exert so that the game will terminate within a given time and energy cost. The mobility player seeks to minimize and the terrain player seeks to maximize this cost.

9084-8, Session 1

Autonomous self-righting using recursive Bayesian estimation to determine unknown ground angle

Jason Collins, Engility Corp. (United States); Chad Kessens, U.S. Army Research Lab. (United States)

As robots are deployed to dynamic, uncertain environments, their ability to discern key aspects of their environment and recover from errors becomes paramount. In particular, tip-over events can potentially end or substantially disrupt mission performance and jeopardize asset recovery. To facilitate recovery from tip-over events (i.e. self-righting), the robot should be able to discern the ground angle on which it lies, even when it is not in its preferred upright orientation. In this paper, we present a methodology for accurately determining ground angle using recursive Bayesian estimation which is robust to robot orientation. First, we briefly review our previous framework for autonomous self-righting, which we use to generate conformation space maps correlating robot configuration and orientation to ground angle. Using these maps, we compare predicted orientation to sensor orientation for the robot configuration given by the sensors on various ground angles. We then assign a probability to each possible ground angle based on the stability margin generated by our conformation space map. We show ground angle prediction error as a function of time using this method, as well as a sensitivity analysis comparing accuracy as a function of the discretization of the ground angle dimension of the conformation space map. Finally, we demonstrate a physical robot's ability to self-right on unknown ground using this methodology.

9084-9, Session 1

Multi-arm multilateral haptics-based immersive tele-tobotic system (HITS) for improvised explosive device disposal

David Erickson, Defence Research and Development Canada, Suffield (Canada); Hervé Lacheray, Gilbert Lai, Amir Haddadi, Quanser Inc. (Canada)

Of great interest to industry, academia, and military is the development of effective improvised explosive device (IED) disposal technology to minimize risk to personnel in activities such as explosive ordnance disposal and mine field clearing. This paper presents the latest advancements in the development of the Haptics-based Immersive Tele-robotic System (HITS), a next generation mobile IED disposal robotic platform. In particular, the paper describes an immersive telepresence environment for a remotely-controlled three-articulated-robotic-arm system, tailored to be mounted on an unmanned ground vehicle. While the haptic feedback provided by the dual-arm tele-operated manipulator enhances the operator's perception of the remote environment, a third tele-operated dexterous arm, equipped with an RGB-D sensor and two high-definition cameras, is used to provide 3D vision, augmented reality, and a 3D photo-realistic model of the potential IED. This decentralized system incorporates elements of real-time stereoscopic vision with augmented reality, head-tracking, live and dynamic IED 3D vision modeling and inspection, multilateral tele-operation with high-transparency haptic feedback, real-time active collision detection and avoidance, and a remote operator control station with immersive interfaces (e.g., haptics, visual, auditory). Experimental results and validation of the current system are presented. Demonstrated performance and capabilities include IED disposal, tool handling (e.g., probe, spade), and duffel bag inspection. Moving forward, HITS provides many avenues for evaluation and expansion. The aim of this multi-year project is to provide remote operators an intuitive interface with expanded sensory input to perform complex tasks to defeat IED's successfully.

9084-10, Session 1

Investigating operator aids for autonomous unmanned ground vehicles

Arthur W. Evans III, U.S. Army Research Lab. (United States)

The research described here investigated the ability of operator knowledge management aids to help increase operator performance and reduce perceived workload, providing the potential for increased mission effectiveness. Specifically, the operator aids provided gave information about what an autonomous robotic asset perceived in the environment and the robotic asset's intended actions based on that information. Twenty subjects completed a total of 7 experimental missions, using a simulated operator control station called the WMI (Warfighter Machine Interface). The missions included various configurations using 3 different operator aids. The operator aids included a long term planner, a short term planner, and an obstacle map. During the simulated missions, participants managed the autonomous robotic asset while completing a reconnaissance task. In addition, participants were expected to identify when the robotic asset had deviated from its intended course and determine why it had done so. Results of this study showed that the use of operator aids had little effect on operator performance, but significantly reduced both cognitive and temporal workload. This reduction in workload, especially with the information presented in the overlays, could let operators take a proactive approach to supervision, rather than simply responding to errors and trouble.

9084-11, Session 1

Speech and gesture interfaces for squad level human robot teaming

Jonathan T. Harris, Daniel Barber, Univ. of Central Florida (United States)

As the adoption of semi-autonomous unmanned systems increases in military use, utilizing redundant and intuitive interfaces for communication between Soldiers and robots is vital to mission success. Currently, Soldiers use a common lexicon to communicate maneuvers between themselves with speech and visual signals. In order for robots to seamlessly integrate within mixed-initiative teams, they must be able to understand this lexicon. Recent innovations in gaming platforms have led to advancements in speech and gesture recognition technologies, but the reliability of these technologies for enabling communication in human robot teaming is unclear. The purpose for the present study is to investigate the performance of Commercial-Off-The-Shelf (COTS) speech and gesture recognition tools in classifying a Squad Level Vocabulary (SLV) for a spatial navigation reconnaissance and surveillance task. The SLV for this study was based on findings from a survey conducted with Soldiers at Fort Benning, GA. During the survey, Soldiers answered questions regarding how they would instruct a robot to execute reconnaissance and surveillance tasks using speech. Resulting commands taken from survey finds were then converted to equivalent arm and hand gestures leveraging existing signals (e.g. U.S. Army Field Manual for Visual Signaling). A commercially available speech recognition engine and a gesture recognition glove classified these commands given by participants. This paper presents classification accuracy of these devices for both speech and gesture modalities independently and combined.

9084-12, Session 1

New generation of human machine interfaces for controlling UAV through depth-based gesture recognition

Tomás Mantecón, Carlos Roberto del Blanco, Fernando Jaureguizar, Narciso García, Univ. Politécnica de Madrid (Spain)

New forms of natural interactions between human operators and UAVs (Unmanned Aerial Vehicle) are demanded by the military industry to achieve a better balance of the UAV control and the burden of the human operator [1]. In this work, a human machine interface (HMI) based on a novel gesture recognition system using depth imagery is proposed for the control of UAVs. Hand gesture recognition based on depth imagery is a promising approach for HMIs because it is more intuitive, natural, and non-intrusive than other alternatives using complex controllers [2]. The proposed system is based on a Support Vector Machine (SVM) classifier that uses spatio-temporal depth descriptors as input features. The designed descriptor is based on a variation of the Local Binary Pattern (LBP) technique to efficiently work with depth video sequences. Other major consideration is the especial hand sign language used for the UAV control. A tradeoff between the use of natural hand signs and the minimization of the inter-sign interference has been established. This has led to an efficient hand-sign vocabulary that on the one hand maximizes the recognition task, and on the other hand minimizes the difficulty and stress of the human operator in its execution. Promising results have been achieved in a depth based dataset of hand gestures especially developed for the validation of the proposed system.

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9084-35, Session Posters-Tuesday

A practical approach to considering uncertainties in the creation of autonomous behaviors in unmanned surface vehicles

Zi Jing Bay, Yip Fatt Lee, Kwok Wai Yue, Ai Peng New, Hao Yi Gan, DSO National Laboratories (Singapore)

Unmanned Surface Vehicles (USV) have been proposed for use in several mission critical operations such as Harbor Defense, Force Protection, Mine Counter Measures (MCM) and Terrorism Deterrence. Despite the varieties of USV systems available in the market, many are still tele-operated systems. Such systems face limitations in operational range due to restrictions of the associated communication technologies. It also increases the workload of the operators during operation as full attention is required while navigating the USV. USV systems with autonomous behaviors can possibly alleviate the operational range and operator's workload constraints by allowing the USV to navigate or achieve specific tasks autonomously. Today, though many autonomous behaviors have been developed in the research community, most face difficulties in showing full functionality in USV systems due to limitations imposed by imperfect perception of the environment and uncertainties in platform control. This paper presents a practical approach in considering these issues during the creation of simple autonomous behaviors such as Obstacle Avoidance (OA) and Target Following (TF) behaviors.

This approach has been successfully demonstrated on a 9-meter USV. Obstacle Avoidance (OA) and Target Following (TF) behaviors were designed and developed using this approach and results have shown that this approach allows the autonomous behaviors to consider imperfect sensor information and control actions during planning.

In this paper, a brief overview of the USV software and hardware system architecture will be presented. Algorithms used to design the USV behaviors and test results will also be explained. Existing problems and future possible developments will be discussed as well.

9084-36, Session Posters-Tuesday

HALOS: fast compact, autonomous adaptive optics for UAVs

Geoff P. Andersen, Paul Gelsinger-Austin, Phani Gaddipati, Ravi Gaddipati, Fassil Ghebremichael, Hua, Inc. (United States)

We present an adaptive optics system which uses a multiplexed hologram to deconvolve the phase aberrations in an input beam. The wavefront characterization is extremely fast as it is based on simple measurements of the intensity of focal spots and does not require any complex calculations. Furthermore, the system does not require a computer in the loop and is thus much cheaper, less complex and more robust as well.

A fully functional, closed-loop prototype incorporating a 32-element MEMS mirror has been constructed. The unit has a footprint no larger than a laptop but runs at a bandwidth of 100kHz – over an order of magnitude faster than comparable, conventional systems occupying a significantly larger volume. Additionally, since the sensing is based on parallel, all-optical processing, the speed is independent of actuator number – running at the same bandwidth for one actuator as for a million.

We are developing the HALOS technology with a view towards next-generation surveillance systems for extreme adaptive optics applications. These include imaging, lidar and free-space optical communications for unmanned aerial vehicles and SSA. The small volume is ideal for UAVs, while the high speed and high resolution will be of great benefit to the ground-based observation of space-based objects.

9084-37, Session Posters-Tuesday

Use of eternal flight unmanned aircraft in operations

Zafer Kok, Turkish Air Force Academy (Turkey)

Unmanned Aerial Systems (UAS), are planed to use solar energy, are being more common and interesting gradually. Today, these systems are very promising while fossil fuels are diminishing rapidly. Development studies on unmanned aerial systems to use the energy, stored daytime, during the night are being conducted by the academic circles. Development of unmanned aerial systems which have eternal flight or very long loiter periods, can be possible by such an energy management. An UAS which can fly very long time can provide many advantages that can not be obtained by conventional aircrafts and satellites. Such systems can be operated as fixed satellites on missions with very low cost in circumstances that require continuous intelligence. By improving automation systems these vehicles can be settled on operation area of automously and can be grounded easily for case of necessities and maintenance. In this paper, the effect of solar powered UAS on operation area has been done as literature review while used in surveillance and reconnaissance missions.

9084-38, Session Posters-Tuesday

Roll angle measurement using a polarization scanning reference source

Harbans S. Dhadwal, Jahangir Rastegar, Varun Kankipati, Omnitek Partners, LLC (United States)

Determination of the roll angle of a projectile, relative to the earth or another mobile platform, is an ongoing topic of interest for guidance and/or steering. Currently available sensors, which include optical line of sight, inertial, RF antennas painted on the projectile, and magnetometers, do not provide an acceptable on-board solution. We present a viable solution, which recovers the instantaneous roll position of an unmanned vehicle by processing the temporal signature produced at the on-board receiver by a polarization scanning reference source. Traditional, polarization based sensors utilize the sinusoidal power fluctuation as the angle between the linear polarization states of the transmitter and receiver are varied. However, these sensors require an independent measurement of the reference power and do not provide a unique solution as the power fluctuations can arise from a number of other sources. By using a polarization scanning reference source, together with a priori knowledge of the temporal signature, the roll angle measurements are robust and independent of power fluctuations at the receiver, which may be due intentional jamming.

Experimental trials, performed in a busy parking lot over a distance of 0.15 miles using a transmitter power of 30 dBm, confirm the efficacy of the technique for both line of sight and non-line of sight scenarios. In this initial study, the state of polarization of the transmitted microwave signal at 10 GHz is defined by the E-plane of a 10-dB horn, which was mounted on a scanning platform, driven by a stepper motor. A full-scan (-90o to 90o) of the linearly polarized carrier is completed in 0.3 s. The receiver comprised of a 10-dB horn, fixed to the projectile and looking backward toward the source, and a logarithm RF detector. The voltage output provides the instantaneous measurement of the carrier power, which contains synchronizing temporal markers for unambiguous roll angle recovery, even in the presence of high background noise.

9084-39, Session Posters-Tuesday

Tiered approach to autonomous radiation search

John S. Clemmensen, Remote Sensing Lab. (United States)

The use of autonomous vehicles in the search and reconnaissance mission space in recent years has shown many benefits to include the ability to search a large area with minimal human footprint, reducing the risk

to humans by removing them from the equation, and improving the success potential of the mission by utilizing modern pre-planned search algorithms. These facts made autonomous vehicles, specifically Unmanned Aerial Vehicles (UAVs) and Unmanned Ground Vehicles (UGVs) ideal for incorporation into the radiation search operation. A current concept of operations for a radiation search mission implements a tiered approach where a small group of specialists integrate into a larger force that can then search/survey an area much quicker than the small group of specialists. The lead specialist directs the search by having the larger force, with basic equipment, execute a preplanned set of sweeps (derived from modern search algorithms) in the search area, which ensures maximum coverage. Then, when an area of interest is discovered, the lead specialist deploys specialized operators with precision equipment to adjudicate the area. The specialized units move within the search area in a more intelligent manner, prioritizing areas of interest based on asset location and outside intelligence. This paper proposes the incorporation of UAVs and UGVs into the radiation search mission as the larger force and more specialized force respectively. UAVs have the ability to sweep large areas while UGVs have the precision required to adjudicate specific targets identified in the larger sweeps. Specifically discussed is the concept of connecting both UAVs and UGVs through a common communications network to a central operation planning node to ensure cohesiveness throughout the mission execution. A central node can compile the data from multiple UAVs and build a prioritized list to deploy Unmanned Ground Vehicles (UGVs). Using autonomous vehicles in this way during a radiation search allows for the most efficient use of resources and optimizes detection probability.

9084-40, Session Posters-Tuesday

The control of armed unmanned air vehicle by joint terminal attack controller in close air support missions

Ahmet Emre Kumaš, Turkish Air War College (Turkey)

With advancing technology, capabilities of UAV(Unmanned Air Vehicle) s are increasing rapidly. Especially the evolution of sensor, data link and control systems creates new concepts of deploying this capable machines. Also they have precision guided munitions. This rapid development provides new using areas and options in the theatre. One of this area is CAS (Close Air Support). The control of these armed aircrafts from thousands of nautical miles by satellite, causes some tactical and ethical problems. Yet CAS missions requires a high level of situational awareness, good Air-Land Integration and precision. In fact, unlike the other UAV tasks, there is a friendly element who has a high level of situational awareness in the target area, in CAS missions. He is an Air Force personel: JTAC (Joint Terminal Attack Controller). He has two sided view (surface level and camera) and real feelings. On the other hand, UAV operator is too far away from the area and the camera provides him a limited visibility. In this study JTAC's and UAV operators situational awarenesses was compared and an answer was tried to be find to the question of who should use the weapons. A literature review about UAVs and CAS missions was made. Last air operations was examined. NATO and national Air Force and Army personel were consulted during the research phase. A SWOT analysis was made to expose the advantages and disadvantages of both options. As a result, both options can be used in different conditions with given rules of angagement.

9084-41, Session Posters-Tuesday

A distributed equipment monitoring and remedial control system based on a collaboration paradigm

Tom Freund, Dig.y.SoL™ (United States)

A distributed collaboration paradigm enables continuous active oversight of equipment operating within a networked environment. This paradigm enables, wherever possible, remedial control actions that mitigate the effects of degraded behavior in line replaceable units (LRU').

9084-42, Session Posters-Tuesday

Calculation and simulation of hydrodynamic forces for a novel detecting spherical robot

Yansheng Li, Hanxu Sun, Yanheng Zhang, Beijing Univ. of Posts and Telecommunications (China); Ming Chu, Beijing Univ. of Posts and Telecommunications School of Automation (China); Qingxuan Jia, Beijing Univ. of Posts and Telecommunications (China); Xiaojuan Lan, Beijing University of Posts and Telecommunications School of Automation (China)

At present, exploring the vast unknown fields (including space and ocean) has become a hot spot in the various agencies, As a moving carrier?the mobile intelligent robot plays an important role, such as communication base stations and observation platform. In order to adapt to a variety of working conditions?a new type of robot was proposed, which can move freely on land or in water with a circular shell, a single propeller and a pair of heavy pendulum. The pendulum inside the robot is used to adjust the attitude, which makes the robot move flexibly, and the circular shell has the excellent compression capability. In order to analyze the kinematics and dynamics characteristics in water, the hydrodynamic forces are studied before the manufacture by CFD simulation, which is a feasible method. It shortens the test cycle, and reduces the cost of the test. The new type of spherical robot is simplified into two kinds of finite element models. The experiments of robot for straight shipping and oblique shipping were simulated, in which the drag forces related with the line speed were determined; The experiments of robot for swaying and yawing were simulated, in which the added mass coefficients related with acceleration were determined. The experiments of robot for cantilevered pool were simulated, in which the rotational coefficients related with angular speed were determined. Through the above calculation and contrast, the comprehensive hydrodynamic results can be analyzed, which saved time for the initial design of robots and also proved that the robot has an outstanding ability underwater.

9084-44, Session Posters-Tuesday

The auxiliary navigation unit and working mechanism for UAVs

Adem Çakir, Turkish Air Force Academy (Turkey)

In the future lots of countries thinking highly of their defense and security programs. Because of their population and probability of losing highly professional personnel makes the countries depending on unmanned vehicles. In the future most of the threats will come from cyber space. Besides having latest software and hardware, ISR systems, self protection systems, integrated weapon systems, also C4 systems will be on the unmanned platforms. For aircraft systems its vital for having minimum one or two subsidiary system. Because of depending highly of cyber space based systems the UAVs should have a secondary system or systems made by fully mechanic not by another cyber space based system or systems. Thus if any cyber attack come from the enemy/enemies the UAVs may change the working system to mechanical one. Lots of the past examples shows us it is possible to create a fully mechanic auxiliary system for UAVs.

9084-45, Session Posters-Tuesday

Current and future possibilities of V2V and I2V technologies: an analysis directed toward augmented reality systems

J. Alejandro Betancur, Andrés Yarce, Aida K. Arnedo, Gilberto Osorio, Univ. EAFIT (Colombia)

Nowadays, It is very important to explore the qualitative characteristics of autonomous mobility systems in automobiles, specially disruptive

technology like Vehicle2Vehicle (V2V) and Vehicle2Infrastructure (V2I), this, in order to comprehend how it will be developed the next generation of automobiles. This paper covers a general review about active safety in automobiles where V2V and V2I systems has been implemented. The goal of this work is to identify the more realistic systems related to V2V and V2I technology, analyzing the current applications, some systems in developing process and some future conceptual proposals. In this way, it is notorious the developing potential of mixing V2I and V2V systems with proposals related to increase the visibility of driver's attention; therefore, it is proposed a combined configuration between this two technologies and an augmented reality system for automobiles like HUD (Head-Up Display), been projected for this kind of configuration an huge potential of implementation once the normative and the roadmap for its development can be established.

9084-46, Session Posters-Tuesday

A 10 GHz polarization scanning reference source

Harbans S. Dhadwal, Jahangir Rastegar, Omnitek Partners, LLC (United States)

Real-time roll angle measurement of an unmanned vehicle, relative to the earth or another mobile platform, is critical for flight control and guidance. We present a viable solution, which recovers the instantaneous roll position by processing the temporal signature produced at the on-board receiver by a polarization scanning reference source. By using a polarization scanning reference source, together with a priori knowledge of the system response, the roll angle measurements are robust and independent of power fluctuations at the receiver, which may be due intentional jamming. Any arbitrary state of linear polarization decomposes into two orthogonal components having dissimilar amplitudes but in phase unison. Thus, a transmitter comprising of two linear polarizations, fed with amplitude, modulated excitation, can generate a linearly polarized reference source. The scan range and rate is a function of the instantaneous amplitudes and frequency of the modulating signal. This approach is distinctly different from techniques based on Faraday rotators or mechanical rotation of half-wave retarders. Measurement of the state of polarization of a RF signal is critical for interpretation of received signals, in other areas of measurement, such as, weather systems, noncontact vibration transducer systems and in general, all measurement systems based on polarimetry; all these will benefit from a polarization scanning reference source.

A proof of concept system comprising discrete components, which include a 10 GHz oscillator, a 3-dB splitter, two variable gain amplifiers, a voltage controlled phase shifter generate a scanning polarized reference source. A polarization scan range of 25o to 65o was possible. Measurements performed in an anechoic chamber, using a 16 dB pyramidal dual polarization horn transmitter antenna and a receiving 10 dB horn, coupled to a RF envelope log-detector, confirm the utility of the proposed scheme. Temporal data recorded using an ADC data acquisition system is processed to recover the single scan data. In particular, data shows how the electronic polarization scanning system can be adapted to measure the role angle of a UAV. Synchronized polarization scanning offers a very robust deployment for both line-of-sight and non-line-of-sight scenarios. The voltage output provides the instantaneous measurement of the carrier power, which contains synchronizing temporal markers for unambiguous roll angle recovery, even in the presence of high background noise.

9084-47, Session Posters-Tuesday

UCAV's: What capabilities must be?

Ramazan Ekici, Harpak (Turkey)

UCAV (unmanned combat air vehicle) is very common nowadays. They are expected future of aircrafts. Some countries are getting more attention to the UCAV's than the others because of the global war on terror.

We use UCAV's at attacks in low threat environment, but in high risk area can we do the same? What are the capabilities of the UCAV's? I want to explain self protection features of the UCAV's. What can we add on these features in future? In Afghanistan, Iraq and Unified Protector, UCAV's get great successes but do they have adversaries who use SAM's and air intercept aircrafts. We see that at beginning of the war in Unified Protector, Strike aircrafts clear SAM threats and then UCAV's are used. What can they do with engaged SAM's? How about their maneuvers and self protection capabilities? And the problem begins here. The Iraq operation shows that they don't have enough capabilities.

Because of not enough capabilities, how do we integrate UCAV's with manned system to the National Air Space (NAS)? At the future (long term), UCAV's are expected fully autonomous. They are managed by artificial intelligence, their decision may be asked. Also they must work together with manned systems.

9084-7, Session 3

Tip-over prevention through heuristic reactive behaviors for unmanned ground vehicles

Kurt A. Talke, SPAWARSYSCEN Pacific: San Diego (United States); Leah Kelley, SPAWARSYSCEN Pacific: San Diego (United States) and Massachusetts Institute of Technology (United States); Patrick Longhini, Garret Catron, SPAWARSYSCEN Pacific: San Diego (United States)

Skid-steer teleoperated robots are commonly used by military and civilian crews to perform high-risk, dangerous and critical tasks such as bomb disposal. Their missions are often performed in unstructured environments with irregular terrain, such as inside collapsed buildings or on rough terrain covered with a variety of media, such as sand, brush, mud, rocks and debris. During such missions, it is often impractical if not impossible to send another robot or a human operator to right a toppled robot. As a consequence, robot tip-over results in mission failure.

To make matters more complicated, such robots are often equipped with heavy payloads that raise their centers of mass and hence increase their instability. Should the robot be equipped with a manipulator arm or flippers, it may have a way to self-right. The majority of manipulator arms are not designed for, and are likely to be damaged during self-righting procedures, however, which typically have a low success rate. Some robots are not equipped with manipulator arms or flippers and thus have no self-righting capabilities. Additionally, due to the on-board camera frame of reference, the video feed may cause the robot to appear to be on at level ground, when it actually may be on a slope nearing tip-over. Finally, robot operators are often so focused on the mission at hand they are oblivious to their surroundings, similar to a kid playing a video game. While this may not be an issue in the living room, it is not a good scenario to experience on the battlefield. Our research seeks to remove tip-over monitoring from the already large list of tasks an operator must perform.

An autonomous tip-over prevention behavior for a mobile robot with a static payload has been developed, implemented and experimentally validated on two different teleoperated robotic platforms. Suitable for use with both teleoperated and autonomous robots, the prevention behavior uses the force-angle stability measure, experimentally validated previously, to predict the likelihood of robot tip-over and to trigger prevention behaviors.

A unique heuristic approach to tip-over avoidance was investigated, wherein a set of evasive maneuvers an expert teleoperator might take are activated when the tip-over-likelihood estimate passes a critical threshold. This control approach was validated on an iRobot Packbot as well as on a Segway RMP 440. The heuristic laws demonstrated the advantage of alerting the operator to a tip-over scenario and gave them more time to correct the situation, as well as the ability to automatically correct the scenario "on the fly".

This research shows promise in preventing dangerous scenarios that could damage a robot and/or compromise its mission, thus saving lives. It further provides a good basis for follow-on research involving the expansion and integration of the prevention-control algorithms, to include movable payloads, environment manipulation, 2D or 3D look-ahead laser sensing and mapping, and adaptive path planning.

9084-13, Session 3

Supporting task-oriented collaboration in human-robot teams using semantic-based path planning

Daqing Yi, Michael Goodrich, Brigham Young Univ. (United States)

As robot sensing, perception and decision-making improves, the human's role in human-robot interaction progressively shifts from teleoperator to supervisor to teammate. This shift toward human-robot teaming means that concepts from human-human teaming become more important, particularly the role of shared mental models to facilitate mutual understanding and ground communication. Of particular importance is how shared mental models enable a more collaborative approach to problem solving, facilitated by communications that operate at a higher, more tactical or strategic level of abstraction.

When human-robot teaming requires task-oriented collaboration in the real world, it is often necessary for the robot to translate a human's verbal command into a sequence and schedule of robot motions. Task grammars and semantic labels of objects in the world enable this translation and therefore serve as the basis for how a robot builds a mental model to understand the human's commands. For example, if a human tells a robot to "carefully screen the back door", this command defines the task as a "screen" task, defines "back door" as constraining the task to specific work region, and defines "carefully" as objective functions that dictates how the task is done (e.g., avoid collisions and move smoothly). We assume a task grammar that specifies a task, one or more constraints, and one or more adverbs that specify how the task should be performed or how the constraints should be managed.

More generally, a verbal command from a human contains multiple objectives and constraints, which means that the robot's path-planning problem is a multiobjective optimization problem. Following related work on blending metric-based and topological approaches to path planning, we propose a two-layer approach by which a robot interprets the human's command and translates this into a sequence of motions. A waypoint layer generates a sequence of waypoints that satisfy the task objectives and constraints. Given this coarse level of planning, the motion planning layer generates the trajectories connecting two neighboring waypoints in a way that satisfies the adverbial modifiers to the task or constraints.

Multiple objectives inherently exist in both layers of planning because adverbial modifiers from the human do not "cleanly" map to unique metric-based performance objectives. We present an efficient framework of optimized path-planners that can be flexible and adaptive to new forms of objective definitions from new scenarios and new information sources. Furthermore, we claim that the solutions generated by these planners are Pareto optimal, which means no objective can be improved without degrading other objectives. This property is important because it means that information communicated from the planners to the human can represent the inherent tradeoffs in satisfying the adverbial modifier and allow the human to refine their intent by selecting among these tradeoffs.

9084-14, Session 3

Determinants of system transparency, and its influence on trust in and reliance on unmanned robotic systems

Scott Ososky, Tracy Sanders, Florian Jentsch, Peter Hancock, Univ. of Central Florida (United States); Jessie Chen, U.S. Army Research Lab. (United States)

Increasingly autonomous robotic systems are expected to play a vital role in aiding humans in complex and dangerous environments. It is unlikely, however, that such systems will be able to consistently operate with perfect reliability. Even less than 100% reliable systems can provide a significant benefit to humans, but this benefit will depend on a human operator's ability to understand a robot's behaviors and states. The notion of system transparency is presented as a vital aspect of robotic design, in maintaining humans' trust in, and reliance on increasingly automated platforms. System transparency is described as the degree to which a system's action, or the intention of an action, is apparent to human operators and/or observers. While the physical designs of robotic systems have been demonstrated to greatly influence humans' impressions of robots, determinants of transparency are not solely system-centric. In this paper, we present insights from our interdisciplinary approach to improving system transparency for the specific application of futuristic human–robot teams. These are teams in which robot agents will autonomously collaborate with humans to achieve task goals. This paper will demonstrate how factors such as human mental models regarding robots, and human–robot communication modality can positively or negatively impact a human's ability to recognize the actions or states of an automated system, even when those systems are highly reliable, yet still imperfect. Furthermore, we will discuss the implications of system transparency on other critical HRI factors such as perceptions of trust, situation awareness and operator workload.

9084-15, Session 3

An interdisciplinary taxonomy of social cues and signals in the service of engineering robotic social intelligence

Travis J. Wiltshire, Emilio J. Lobato, Jonathan Velez, Florian Jentsch, Stephen M. Fiore, Univ. of Central Florida (United States)

Understanding intentions is a complex social-cognitive task for humans, let alone machines. One promising approach working towards addressing this need is the multidisciplinary field of Social Signal Processing because it entails a useful distinction between social cues and social signals. In this paper, we describe the development of a framework describing parameters associated with social cues and social signals. This framework is based upon an interdisciplinary integration of theory and concepts from social cognition research but adapted for development in human-robot interaction. The aim of this taxonomy is to further the development of robotic social intelligence to better facilitate natural interactions between humans and robots. This is warranted given that a common problem facing researchers in this area is that the literature is presently limited in the degree in which it provides a cohesive framework that specifies: (1) the sensors used for detecting social cues, (2) the parameters for differentiating and classifying differing levels of those cues, and (3) how sets of social cues indicate specific social signals. This is necessarily an iterative process, as technologies improve and social science researchers better understand the complex interactions of vast quantities of social cue combinations. As such, the goal of this paper is to advance a taxonomy of this nature to further stimulate interdisciplinary collaboration in the development of advanced social intelligence that mutually informs areas of robotic perception and intelligence.

9084-16, Session 3

Validation and verification of a high-fidelity computational model for a bounding robot's parallel actuated elastic spine

Jason L. Pusey, U.S. Army Research Lab. (United States); Jeffrey M. Duperret, Daniel E. Koditschek, Univ. of Pennsylvania (United States)

We document the design and preliminary computer simulation of a high fidelity model of Canid, a recently introduced bounding robot. Canid is a free-standing, power-autonomous quadrupedal machine constructed from standard commercially available electromechanical and structural elements, incorporating compliant C-shaped legs like those of the decade old RHex design, but departing from that standard (and, to the best of our knowledge, from any prior) robot platform in its parallel actuated elastic spine. We have developed within a commercial modeling package a finite-element model of the actuated, cable-driven, rigid-plate-reinforced harness for the carbon-fiber spring that joins the robot's fore- and hind-quarters. We compare simulations of this parallel actuated elastic spine model with

empirical data from a series of increasingly dynamic Canid experiments. We first compare the predictions of the carbon-fiber spring model with data taken from the physical spine flexed in isolation from the actuated harness. We next compare the full model with experimental data from the robot in which its rear quarters are locked to ground and the actuated spine assembly is used to exercise the robot's fore-quarters in a quasi-static condition. We finally offer preliminary comparison of the computational model output with data from the rear-locked robot under progressively more dynamical operation. We speculate on what improvements to this simulation model will be required to achieve empirical fidelity sufficient to serve as a design guide for robot control algorithms and further iterations of the platform's redesign.

9084-17, Session 3

Validation and verification of a high-fidelity computational model for a RHex-class robot C-shaped leg

Raymond Von Wahlde, Jason L. Pusey, U.S. Army Research Lab. (United States); Jeffrey M. Duperret, Daniel E. Koditschek, Univ. of Pennsylvania (United States)

The XRHex robot, an updated version of RHex, obtains its mobility characteristics in large part due to its compliant, epoxy-fiber, C-Shaped legs (C-leg). Many RHex-inspired, C-leg simulation models have been proposed in the literature, but their fidelity to its empirical operational performance has never been rigorously examined in the scientific literature. Here, we document the design and preliminary numerical exercise of a high fidelity, segmented, lumped-compliance model of the XRHex C-leg, developed within a commercial modeling package. We compare simulations of this C-leg model with empirical data from a series of increasingly dynamic XRHex leg experiments. We compare the predictions of the model of the leg with data taken from the leg flexed in isolation from the motor drive train. We also try to characterize the stiffness of the C-leg by spinning it in a horizontal plane and capturing, via high speed camera, its deflection due to centrifugal force. We next compare the model with experimental data from the robot in which its body is immobilized above a slippery force-plate across which a single leg is driven by the robot's hip motor in a quasi-static condition. Finally, we offer preliminary comparison of the model output with data from the hip-locked leg under progressively more dynamical operation. We speculate on what improvements to this simulation model will be required to achieve empirical fidelity sufficient to serve as a design guide for robot control algorithms and further iterations of the platform's redesign.

9084-18, Session 3

Temporally consistent segmentation of point clouds

Jason L. Owens, U.S. Army Research Lab. (United States); Philip Osteen, Engility Corp. (United States); Kostas Daniilidis, Univ. of Pennsylvania (United States)

Generating a useful segmentation for a point cloud is an important prerequisite for object recognition, grasping, and scene understanding. Existing work has focused on single-frame segmentation in images or RGB-D image pairs, or global segmentations in a finalized point cloud. In robotics applications, however, we have dynamic control over the sensor viewpoint within the environment and a constant stream of data from sensors making the single-frame or finalized point cloud approach less desirable, especially during navigation or manipulation related tasks where an up-to-date segmentation can be critical. While it may be possible to re-segment the entire cloud at every frame, it is not clear how to maintain consistency between completely different segmentations. Therefore, we consider the problem of generating temporally consistent point cloud segmentations from streaming RGB-D data, where every incoming frame extends existing labels to new points or contributes new labels while maintaining the labels for pre-existing segments. Our approach uses a basic single-frame over-segmentation based on normalized cuts, where the edge weights in the adjacency graph are calculated from the proximity and differences between point normals. Given the data stream from a potentially mobile sensor, we solve for the camera transformation between consecutive frames using a joint optimization over point correspondences and image appearance. The aligned point cloud may then be integrated into a consistent model coordinate frame. Previous point labels are propagated forward to corresponding points as the new frame is integrated, while new points not determined to belong to existing segments are assigned new labels. We evaluate our algorithm on existing as well as newly-generated RGB-D datasets with dense segmentation ground truth.

9084-19, Session 3

Common world model for unmanned systems: phase 2

Robert M. Dean, General Dynamics Land Systems (United States)

The Robotics Collaborative Technology Alliance (RCTA) seeks to provide adaptive robot capabilities which move beyond traditional metric algorithms to include cognitive capabilities. Key to this effort is the Common World Model, which moves beyond the state-of-the-art by representing the world using semantic, symbolic as well as metric information. It joins these layers of information to define objects in the world. These objects may be reasoned upon jointly using traditional geometric, symbolic cognitive algorithms and new computational nodes formed by the combination of these disciplines to address Symbol Grounding and Uncertainty. The Common World Model must understand how these objects relate to each other. Our world model includes the concept of Self-Information about the robot. By encoding current capability, component status, task execution state, and their histories we track information which enables the robot to reason and adapt its performance using Meta-Cognition and Machine Learning principles. The world model also includes models of how entities in the environment behave which enable prediction of future world states. To manage complexity, we have adopted a phased implementation approach. Phase 1, published in these proceedings in 2013, presented the approach for linking metric with symbolic information and interfaces for traditional planners and cognitive reasoning. Here we discuss the design of "Phase 2" of this world model, which extends the Phase 1 design with 3D representations, Inter-visibility, Dynamic (moving) Objects, hypothesized Semantic Objects, and additional outputs for Human Robot Interaction.

9084-20, Session 3

Field demonstration of an autonomous small ground robot using a MEMS-scanned ladar

Michael A. Powers, General Dynamics Robotic Systems (United States); Barry L. Stann, Mark M. Giza, U.S. Army Research Lab. (United States)

LADAR is among the pre-eminent sensor modalities for autonomous vehicle navigation. Size, weight, power and cost constraints impose significant practical limitations on perception systems intended for small ground robots. In recent years, ARL developed a LADAR architecture based on a MEMS scanner that fundamentally improves the trade-offs between these limitations and sensor capability. We describe how the characteristics of a highly developed prototype correspond to and satisfy the requirements of autonomous navigation and the experimental scenarios of the Robotics Collaborative Technology Alliance (RCTA) program. In particular, the long maximum and short minimum range capability of the ARL MEMS LADAR makes it remarkably suitable for a wide variety of scenarios from building mapping to the manipulation of objects at close range, including dexterous manipulation with robotic arms. A prototype system was applied to a small (approximately 50 kg) unmanned robotic vehicle as the primary perception sensor. We present the results of a field test where the perception information supplied by the LADAR system successfully accomplished the experimental objectives of an Integrated Research Assessment (IRA).

9084-21, Session 3

Autonomous whole-body locomotion via three-dimensional visual sensing

Matthew Travers, Carnegie Mellon Univ. (United States)

Autonomous robotic systems have demonstrated limited success until very recently. One reason for the relatively slow pace of this development is that autonomy requires many different subsystems to all work interdependently. In reality each subsystem itself addresses a difficult problem, e.g., nonlinear control, computer vision, cognition, etc. Subsequently combining these subsystems as a single machine has proven to be a very difficult problem.

This work presents an initial attempt to fuse an advanced vision system with a unique mobility platform. The vision system consists of a structured light sensor composed of a laser line projector and a black and white camera. The platform is a modular snake robot, a whole-body locomotor, that is capable taking on three-dimensional shapes. The goal of combining these systems is to make it possible for the platform to execute autonomous mobile behaviors.

Snake robots have previously demonstrated measured success at semi-autonomous behavior, but in each demonstration were heavily reliant on operator intervention. The goal of this work is to show that by using a vision system, capable of mapping three-dimensional scenes, the operator can be removed from the control loop. To demonstrate the efficacy of this hybrid vision-mobility system we focus on two target behaviors: 1.) autonomously finding and climbing a pole and 2.) autonomously navigating and mapping a network of pipes. In both cases the snake robot will use its internal joint angles to move the sensor and collect local data. Several algorithms that efficiently process and interpret the returned point clouds will be discussed.

9084-22, Session 6

Object guided autonomous exploration for mobile robots in indoor environments

Carlos P. Nieto-Granda, Siddarth Choudhary, Henrik I. Christensen, Georgia Institute of Technology (United States)

Nowadays, robot exploration strategies are decided for specific tasks like mapping or finding specific objects in an unknown environment. Our goal is to provide semi-autonomous exploration strategies based on the objects of interest, provided by a human operator, in order to identify a potential hazardous device during a military or civilian surveillance operation.

In this paper the authors describe the results of the experiments on behalf of the MAST CTA. The semantic information available in objects provide better model for the interaction between human operator and robots. Objects integrate both shape and texture information into a coherent model. The robot chose the best exploration strategy to produce the optimal object model which provided more visual information to a human team. The performance of our experiments were evaluated in different indoor scenarios using two different mobile platforms.

9084-23, Session 6

Development and evaluation of the Stingray: an amphibious maritime interdiction operations unmanned ground vehicle

Hoa G. Nguyen, Mendel Baker, Space and Naval Warfare Systems Ctr. Pacific (United States); Robin Castelli, Macro USA Corp. (United States)

The U.S. Navy conducts thousands of Maritime Interdiction Operations (MIOs) every year around the globe. Navy Visit, Board, Search, and Seizure (VBSS) teams regularly board suspect ships and perform search operations, often in hostile environments. There is a need for a small tactical robot that can be deployed ahead of the team to provide enhanced situational awareness in these boarding, breaching, and clearing operations. In 2011, the Space and Naval Warfare Systems Center Pacific conducted user evaluations on a number of small throwable robots and sensors, verified the requirements, and developed the key performance parameters (KPPs) for an MIO robot. A paper was presented at this conference (Unmanned Systems Technology XIV) summarizing the study and resulting KPPs. A contract was then issued to MacroUSA for the design and development of two prototype systems, each consisting of one control/display unit and two small amphibious robots, named Stingray. Technical challenges in the design include the combination paddle wheel/shock-absorbing wheel, the tradeoff between impact resistance and buoyancy, and achieving adequate traction on wet surfaces. This paper describes the technical design of these robots and the results of subsequent user evaluations by Navy, Coast Guard, and Marine VBSS teams.

9084-24, Session 6

Micro air vehicle autonomous obstacle avoidance from stereo-vision

Roland Brockers, Jet Propulsion Lab (United States); Stephan Weiss, Jet Propulsion Lab. (United States); Lawrence Matthies, Jet Propulsion Lab (United States)

We introduce a new approach for on-board autonomous obstacle avoidance for micro air vehicles that fly out-doors in close proximity to structure. Our approach uses inverse-range, polar-perspective stereo-disparity maps for obstacle detection and representation, and deploys a closed-loop RRT planner that considers flight dynamics for flight trajectory generation.

While the motion planner incorporates vehicle dynamics to generate candidate trajectories in 3D, we perform collision checking directly in disparity space, which reduces obstacle expansion to a 2D operation and collision checking itself to a fast z-buffer-like operation. The small memory footprint of this image-based representation combined with the reduced search space results in a significant performance improvement when compared to traditional 3D methods, making our method feasible to run on small platforms that fly at higher speeds.

We evaluate the robustness of our approach in a virtual simulation environment, and demonstrate the capability of this method with real world flights of a quadrotor system under tree canopy.

9084-25, Session 6

Assisted autonomy of articulated snake robots

David S. Rollinson, Howie Choset, Carnegie Mellon Univ. (United States)

Our lab has developed new capabilities for snake robots that allow them to successfully navigate pipe junctions. Up until now, snake robots have only been able to navigate simple straight sections of pipe, or pipes with small bends. These capabilities have been demonstrated in both a lab environment, as well as a real-world underground storm sewer. Recent development in the control and state estimation of snake robots have enabled these capabilities.

The development of a gait-based compliant controller enables us to develop more complex motions without passing the complexity on to the operator. Previously, the dimensionality of a gait or motion controller was limited, since any parameter would need to be exposed operator and directly controlled. By formulating our low-dimensional controllers as a state estimation problem, we can now prescribe simple control laws that are intuitive to the operator and allow many gait parameters to be controlled autonomously.

New state estimation techniques that exploit the robot's redundant sensing allow accurate estimation even when significant amounts of feedback is missing or corrupted. This has practical advantages in the field in that an operator can have knowledge of the robot's full shape and orientation, even if multiple modules in the robot have failed.

9084-26, Session 6

Counter tunnel exploration, mapping, and localization unmanned system

Jacoby Larson, Space and Naval Warfare Systems Ctr. Pacific (United States)

Cross-border tunnels present a security vulnerability and creates methods of entry for people and contraband to illegally enter the United States. This paper addresses some of the platforms, sensors, and methods used to explore, map, and localize an unmanned system inside a tunnel environment for the purposes of characterizing a tunnel and locating the points of egress.

9084-27, Session 6

On the consistency analysis of A-SLAM for UAV navigation

Ersan A. Oguz, Turkish Air Force Academy (Turkey); Hakan Temeltas, Istanbul Technical Univ. (Turkey)

UAVs are expected to perform all or part of its mission as autonomous in accordance with predefined manufacture objectives and pre-request of safe autonomous navigation. A successful autonomous navigation is based on detection of the UAV's location precisely and simultaneous mapping of the environment. Nowadays the most common method for location detection is the use of Global Navigation Satellite Systems (GNSS). However, it is still a challenge for researchers to determine the location in GNSS denied environments. Although new methods are emerging continuously, the most notable one is Simultaneous Localization and Mapping (SLAM), which is a good choice when both UAV's position and region map are not known.

SLAM has been a popular research topic in the field of robotics for many years. Moreover, its applications on land vehicles are still going on intensively. SLAM is relatively easy to implement in robotics compared to air vehicles. Since robots and land vehicles move at lower speeds in a 2D area, necessary mathematical model is developed in two dimensions only. In contrast, UAVs which move much faster than robots or land vehicles need more complex mathematical models in a 3D environment. This further complicates the application of SLAM technique on UAVs, which is known as Airborne SLAM (A-SLAM). Moreover, kinematic model of a UAV results in a set of nonlinear equations which brings additional complexity. Due to this nonlinearity, Extended Kalman Filter (EKF) and Unscented Kalman Filter (UKF) which are available for nonlinear systems are frequently employed.

In this study, EKF and UKF based A-SLAM concepts are discussed in details by presenting the formulations and MATLAB Simulink model with simulation results. The UAV kinematic model and state-observation models for EKF and UKF based A-SLAM methods are developed to analyze the filters' consistencies. Consistency is defined as the correlation between calculated filter covariance and error. The error is calculated as the difference between UAVs actual and estimated positions. For a consistent filter, it is expected that the error decreases as the calculated filter covariance decreases. However, it is observed that as the iteration goes on, the calculated filter covariance value diminishes as expected while the error does not decrease due to the inconsistency of EKF and UKF based A-SLAM structures. In order to find the root causes of inconsistency, necessary conditions for consistency of the EKF and UKF based A-SLAM structures are described and consistencies of the the methods are consequently investigated by considering these conditions and using simulation results. The analysis during landmark observation exhibits an inconsistency in the form of a jagged UAV trajectory. It is well known that one of the cause of inconsistencies is the accumulation of error due structure of Kalman filter. In addition, in this study it has been found that unobservable subspaces and jacobien matrices used for linearization are two major sources of the inconsistency observed. Moreover, UKF performs better in terms of filter consistency since it does not require jacobien matrix linearization. As a future work, the methods which can be used to increase the consistencies of EKF and UKF based A-SLAM are proposed for better autonomous UAV navigation performance.

9084-28, Session 7

Using infrared cameras to generate range maps for unmanned vehicle navigation

Todd Aycock, David B. Chenault, Polaris Sensor Technologies, Inc. (United States)

Navigation is a critical subsystem for autonomous and unmanned vehicles, and a key component to this subsystem is perception. Through the use of environmental sensing, a vehicle must make decisions which can greatly impact the survivability of the vehicle and success of its overall mission. Of particular importance for perception are the functions of path finding, obstacle detection and avoidance, and localization. In this paper, the authors investigate the use of stereo infrared cameras and real-time range mapping algorithms to augment other sensing techniques in order to enhance these functions in unmanned vehicle applications.

9084-29, Session 7

Infrared stereo calibration for unmanned ground vehicle navigation

Josh Harguess, Space and Naval Warfare Systems Ctr. Pacific (United States); Shawn J. Strange, SAIC (United States)

The problem of calibrating two color cameras as a stereo pair has been heavily researched and many off-the-shelf software packages, such as Robot Operating System (ROS), include calibration routines that work in most cases. However, the problem of calibrating two infrared (IR) cameras for the purposes of sensor fusion and point cloud generation is relatively new and many challenges exist. We present an in-depth comparison of color camera and IR camera stereo calibration using ROS and data from an unmanned ground vehicle. We present the following challenges for IR stereo calibration; calibration patterns, border and pattern detection, image pre-processing and feature matching for point cloud generation. Finally, we present our solution and algorithm for IR stereo camera calibration along with results and reconstruction errors.

9084-30, Session 7

A robust method for online stereo camera self-calibration in unmanned vehicle system

Yu Zhao, Hitachi, Ltd. (Japan)

Self-calibration technology of stereo camera system is important for lots of applications in particular the unmanned system, where calibration system is a fundamental technology used to estimate the relative posture of the cameras for environment recognition.

We focused on the issue of recognition accuracy decrease caused by the vibration of platform. Accordingly, we conducted this research to achieve the on-line self-calibration using feature point's registration and robust estimation of fundamental matrix. In conventional method, some registration algorithms such as SIFT, SURF are used to search the corresponding feature points and RANSAC algorithm is used to estimate the parameter. However three key factors in this respect are still needed to be improved. Firstly, the feature points detection and registration play a central role in the self-calibration procedure. However, in the case of utilizing SURF descriptor registration which is considered as one of the most accurate descriptor registration methods, the mismatching even exists resulting in the decrease of estimation accuracy of relative posture. The second, another key factor in this respect is the estimation method for calculating the Fundamental Matrix which shows the relative posture of stereo camera. The conventional estimation method cannot satisfy both the estimation speed and calibration accuracy at the same tame. The third, it cannot be ignored that there might be some system intrinsic noises caused by the setup of stereo camera system as well as other situations. These noises also lead greatly to the deviation of estimation results.

In order to improve the calibration accuracy, estimation speed and system robustness for the practical implementation, we discuss and analyze the algorithms to make improvements on the stereo camera system to achieve on-line self-calibration. Based on the epipolar geometry and 3D images parallax, two geometry constraints are proposed to make the corresponding feature points search performed in a small search-range resulting in the improvement of matching accuracy and searching speed. Then, two conventional estimation algorithms are analyzed and evaluated for estimation accuracy and robustness. The third, Rigorous posture calculation method is proposed with consideration of the relative posture deviation of each separated parts in the stereo camera system.

Validation experiments were performed with the stereo camera mounted on the Pen-Tilt Unit for accurate rotation control and the evaluation shows that our proposed method is fast and of high accuracy with high robustness for on-line self-calibration algorithm. The posture estimation accuracy is 0.0538 degree in rotation deviation evaluation and 0.46 pixels in epipolar distance evaluation which has about 4 times higher accuracy than the results of conventional methods, moreover our estimation is able to perform in near real-time. Thus, as the main contribution, we proposed method to solve the on-line self-calibration fast and accurately, envision the possibility for practical implementation on unmanned system as well as other environment recognition systems.

9084-31, Session 7

Investigating clutter reduction for unmanned systems applications using imaging polarimetry

Jonathan Hanks, Todd Aycock, David B. Chenault, Polaris Sensor Technologies, Inc. (United States)

The proliferation of unmanned systems in recent years has sparked increased interest in multiple areas of research for on-board image processing including autonomous navigation, surveillance, detection, and tracking to name a few. For these applications, techniques for reducing scene clutter provide an increased level of robustness for autonomous systems and reduced operator burden for teleoperated systems. Because imaging polarimetry frequently provides complementary information to the standard radiometric image, it is anticipated that this technology is well suited to provide a significant reduction in scene clutter. In this paper, the authors investigate the use of imaging polarimetry under a number of representative scenarios to assess the utility of this technology for unmanned system applications.

9084-32, Session 7

Absolute localization of ground robots by matching lidar and image data in dense forested environments

Marwan Hussein, Massachusetts Institute of Technology (United States); Matthew Renner, U.S. Army Engineer Research and Development Ctr. (United States); Karl Iagnemma, Massachusetts Institute of Technology (United States)

A vision-based method for the autonomous geolocation of ground vehicles in forested environments is presented. The method provides an estimate of the global horizontal position of a vehicle strictly based on finding a geometric match between a map of observed tree stems, scanned in 3D by Light Detection and Ranging (LiDAR) sensors onboard the vehicle, to another stem map generated from the structure of tree crowns analyzed from high resolution aerial orthoimagery of the forest canopy. Estimation of stems from 3D data is achieved by using Support Vector Machine (SVM) classifiers and height above ground filters that separate ground points from vertical stem features. Estimation of stems from overhead imagery is achieved by calculating the centroids of tree crowns extracted using a watershed segmentation algorithm. Matching of the two stem maps is achieved by using a robust Iterative Closest Point (ICP) algorithm that determines the rotation and translation vector required to align both datasets. The final alignment is used to calculate the absolute location of the vehicle. The localization algorithm has been tested with real-world data and has been able to estimate vehicle geoposition with an average error of approximately 1.5 m. It is noted that the algorithm's accuracy performance is currently limited by the accuracy and resolution of the aerial orthoimagery used.

This method can be used in real-time as a complement to the Global Positioning System (GPS) and Simultaneous Localization and Mapping (SLAM) in areas where signal coverage is inadequate due to attenuation by the forest canopy, or due to intentional denied access. The method has two key properties that are significant: i) It does not require a priori knowledge of the area surrounding the robot. ii) Based on estimated vehicle state, it uses the geometry of detected tree stems as the only other input to determine horizontal geoposition.

9084-33, Session 7

Occluded human recognition for a following leader using 3D range and image data in forest environment

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This paper describes an occluded target recognition method for a leader-following system using 3D range and image data of an autonomous vehicle in forest environment. 3D range data shows remarkable performance for real-time object detection in a complex environment. Unfortunately, 3D range data has a difficulty in segmenting close encounters with multiple objects. It is one of key problems to easily lose a target, a leader, in a leader-following system for an autonomous vehicle in forest environment. In a case with an occlusion scenario, we show how to efficiently handle splitting and merging objects. In our approach, the ROI (region of interest) of object candidates are extracted from LIDAR sensor and then the two synchronized data, one from LIDAR and the other from camera, are classified into human and tree objects according to features and classifiers. There are two target-association situations in forest environment; tree-human and human-human. In tree-human association, 3D LIDAR information is able to deal with identification of human and tree objects. On the other hand, in human-human association, this ability of LIDAR sensor is not enough performance. The local features of image data give information to cover data association to the same objects. The classification method of LIDAR is working with the combination of NPR (the number of points in a rectangle) and Adaboost, our previous research. The time sequence object matching uses a SIFT (scale invariant feature transform) algorithm in previous extracted ROI. The fusion of each processing results is integrated by Bayesian estimation for recognizing human and tree objects as well as the multi-class classification mechanism is introduced. The propose method is evaluated by forest environment dataset for a leader-following system. Based on the processing, we get each object likelihood of both LIDAR and camera for the further processing of human and tree recognition.

9084-34, Session 7

A fast and robust plane detection method from 3D-lidar data

Hakan Temeltas, Istanbul Technical Univ. (Turkey); Cihan Ulas, TUBITAK UME (Turkey)

In this paper, we introduce a fast and robust plane detection method that combines the Multi-Layered Normal Distributions Transform (ML-NDT) and a feature extraction algorithm into a single framework. This is achieved by first applying the conventional Normal Distributions Transform (NDT) generation process to the reference scan to divide the point cloud into regular cells. This step is also known as discretization or splitting process. After the discretization process, planar segments of each cell are detected by first finding the inliers of a plane via RANSAC algorithm. In our study, performance of RANSAC method is also increased by integrating a Least Entropy Like (LAL) Estimators. Therefore the RANSAC method gains robustness for outliers that severely influence the method. After finding the infinite plane parameters, the convex hull or the minimum rectangular bounding box of the planes are computed. Both convex hull and minimum bounding box computation is based on the projection of the inlier plane points into a plane. After finding the correct transformation, the plane segments are merged by using dynamic region growing algorithm to get large planes as landmarks. Detected planes are merged with respect to satisfaction of orientation, translation and closeness tests. During the plane detection process several useful properties such as plane normal vector, center of gravity, convex hull points, covariance matrix, number of inliers in the plane and plane area can be computed.

Thus, the proposed method provides three significant advantages with respect to conventional methods. The first one is that the proposed method is more robust to outliers since it is based on the matching of certain geometric structures. The second one is that the registration step is much faster because the number of points to be matched is very less with respect to all scanned points. Therefore, this process can be considered as a special sampling strategy. Finally, it is showed that the extracted planes can also be used in feature based probabilistic 3D-SLAM methods. Since the plane segments are already registered, the data association problem can be easily solved even without any odometer measurement. This can be considered as the most powerful part of the algorithm because data association problem in three dimensions is quite difficult problem. As a result, on the one hand, it is obtained a robust and fast scan matching; on the other hand, it is possible to extend the method for feature extraction algorithm in SLAM problems with a little extra computation. The method has been experimentally applied to 3D images acquired by a 3D-Lidar and it is shown that the results are quite satisfied.

Monday - Tuesday 5 –6 May 2014

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9085-1, Session 1

Effects of star crossings on the detection of dim objects in orbit and mitigation strategies for improving detection

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The detection of dim objects in and around the Earth is an important space situational awareness function, in that these objects might be uncataloged space debris, micro-satellites or even small asteroids that could be a threat to our national infrastructure. Detection of dim objects is a challenging task, but the presence of brighter objects in the vicinity makes their detection even more challenging. In this paper the effect of nearby stars on simple point detection algorithms is demonstrated. This analysis shows how bright objects degrade the performance of simple space object detection algorithms that rely on calculations of the local background statistics around the pixel being tested.

The paper also shows how normality tests can be employed for mitigating the effects of star crossings on the detection of dim objects in space by detecting outliers from the background and removing them from the local background statistics calculation. Although the data itself does not possess a Gaussian distribution, the joint log-likelihood of the data should possess a near normal distribution. By computing the joint log-likelihood of the background data pixels, outlier data points can be determined as those that make the log-likelihood non-Gaussian. In this way outliers in the background can be identified and removed from the estimate of the local noise variance. The new outlier rejection scheme is tested in simulation and with measured astronomical data to determine the degree to which it enhances the detection of dimly lit space objects.

9085-2, Session 1

Using ATCOM to enhance long-range imagery collected by NASA's flight test tracking cameras at Dryden Flight Research Center

Petersen F. Curt, Aaron L. Paolini, EM Photonics, Inc. (United States); David Tow, NASA Dryden Flight Research Ctr. (United States); Eric J. Kelmelis, EM Photonics, Inc. (United States)

Located at Edwards Air Force Base, Dryden Flight Research Center (DFRC) is NASA's premier site for aeronautical research and operates some of the most advanced aircraft in the world. As such, flight tests for advanced manned and unmanned aircraft are regularly performed there. All such tests are tracked through advanced electro-optic imaging systems to monitor the flight status in real-time and to archive the data for later analysis. This necessitates the collection of imagery from long-range camera systems of fast moving targets from a significant distance away. Such imagery is severely degraded due to the atmospheric turbulence between the camera and the object of interest. The result is imagery that becomes blurred and suffers a substantial reduction in contrast, causing significant detail in the video to be lost.

ATCOM technology developed by EM Photonics has shown the ability to mitigate the effects of such turbulence on imagery. Working with NASA, we have developed a demonstration device capable of processing data collected by DFRC's flight tracking cameras and enhancing it in order to regain image quality to effectively reach the theoretical diffraction limit of the imaging system. In this paper, we will describe the challenges of imaging in these conditions, how we were able to enhance collected video through image processing, and the design of a system capable of performing this processing in real time.

9085-3, Session 1

FalconSAT-7: a membrane space telescope

Geoff P. Andersen, Olha V. Asmolova, Thomas Dickinson, U.S. Air Force Academy (United States)

The USAF Academy Department of Physics is building FalconSAT-7, a membrane solar telescope to be deployed from a 3U CubeSat in LEO. The primary optic is a 0.2m photon sieve – a diffractive element consisting of billions of tiny holes in an otherwise opaque polymer sheet. The membrane, its support structure, secondary optics, two imaging cameras and associated control/recording electronics are all packaged within half the CubeSat volume. Once in space the supporting pantograph structure is deployed, pulling the membrane flat under tension. The telescope will then be steered towards the Sun to gather images at H-alpha for transmission to the ground.

Due for launch in 2015, FalconSAT-7 will serve as a pathfinder for future surveillance missions. We are currently investigating two possible options optimized for Earth observing and SSA, with a preliminary design consisting of a 0.3m aperture deployed from a 12U satellite. Such a telescope would be capable of providing sub-meter resolution of ground or space-based objects depending on the orbital characteristics.

9085-4, Session 1

Integrated RF/optical space surveillance sensor

Claudia Knez, David Copeland, David Patrone, Norman Adams, Joseph Hennawy, Eric Melin, William Dove, Johns Hopkins Univ. Applied Physics Lab. (United States)

At present, space surveillance relies on telescope and active RF (radar) sensors for object identification, tracking, and characterization. While successful at tracking any manner of objects accurately, radar installations for space surveillance are large and complex installations. Telescopes are also very successful at tracking, but rely on additional information to find the orbit solution, and provide limited information on the target's operational behavior. Passive RF sensors can monitor targets that are actively transmitting in order to provide information lacking in the optical data. An antenna of modest size provides sufficient signal-to-noise ratio (SNR) for signal identification and Doppler tracking. The downlink characteristics of a space object are a critical component to its behavior. The detection and monitoring of these characteristics provide direct, unique observables toward an object's operation that are not available from a telescope or radar. The observables include the frequencies at which it transmits, time(s) of transmission, and data-rate of downlink.

Current space surveillance systems do not tightly integrate RF and optical sensors. Such integration would allow the two domains (RF and optical) to benefit from the strengths of each:

1) A target detected in either domain can quickly be tracked and characterized in both;

2) For optically faint objects, the use of RF tracking allows the telescope to use longer integration times without needing an accurate ephemeris;

3) A continuous track can be maintained on a target that transmits intermittently; the RF sensor could rely on the optical sensor for tracking information during periods of no emission, allowing the RF sensor to characterize the intermittent behavior;

4) An RF sensor can track in adverse weather while an optical sensor can maintain track during RF interference.

A modest sized RF antenna coupled with a small aperture telescope could be deployed in the field as a distributed network of sensors. Current or decommissioned telemetry, tracking, and command (TT&C) ground stations could also be re-tasked as space surveillance sensors, in addition to their communications mission.

We explore and demonstrate the integration of passive RF and optical space

surveillance sensor capability, using the ground station antennas of the Applied Physics Laboratory (APL) Satellite Communication Facility (SCF) and the APL 24-in optical telescope. The integrated sensor provides a multi-dimensional set of observables for transmitting space objects, enabling intelligent analysis to determine a target's mission and intent. We have tracked objects with both the telescope and an SCF antenna using closed-loop tracking on the SCF antenna. We have observed multiple satellites in a constellation to determine their pattern of life of each of the targets.

9085-5, Session 1

SUCHI: the space ultra-compact hyperspectral imager for a small satellite

Sarah T. Crites, Paul G. Lucey, Robert Wright, Univ. of Hawai'i (United States); Jason T. Akagi, Spectrum Photonics, Inc. (United States); Jeremy Chan, Harold Garbeil, Keith Horton, Amber Imai, Mark Wood, Lance Yoneshige, Univ. of Hawai'i (United States)

The primary payload on the University of Hawaii-built 'HiakaSat' micro-satellite will be the Space Ultra Compact Hyperspectral Imager (SUCHI). SUCHI is a low-mass (<9kg), low-volume (10x10x36 cm3) long wave infrared hyperspectral imager designed and built at the University of Hawaii. SUCHI is based on a variable-gap Fabry-Perot interferometer employed as a Fourier transform spectrometer with images collected by a commercial 320x256 microbolometer array. The microbolometer camera and vacuum-sensitive electronics are contained within a sealed vessel at 1 atm. SUCHI will collect spectral radiance data from 8 to 14 microns and demonstrate the potential of this instrument for geological studies from orbit (e.g. mapping of major rock-forming minerals) and volcanic hazard observation and assessment (e.g. quantification of volcanic sulfur dioxide pollution and lava flow cooling rates). The sensor has been integrated with the satellite which will launch on the Office of Responsive Space ORS-4 mission scheduled for 2014. The primary mission will last 6 months, with extended operations anticipated for approximately 2 years. A follow-on mission has been proposed to perform imaging of Earth's surface in the 3-5 micron range with a field of view of 5 km with 5.25 m sampling (from a 350 km orbit). The 19-kg proposed instrument will be a prototype sensor for a constellation of small satellites for Earth imaging. The integrated satellite properties will be incorporated into the Hawaii Space Flight Laboratory's constellation maintenance software environment COSMOS (Comprehensive Open-architecture Space Mission Operations System) to ease future implementation of the instrument as part of a constellation.

9085-6, Session 2

Morphological analysis and characterization of directional emission structures for spacecraft thermal control

Bryan Adomanis, Air Force Research Lab. (United States)

Sub-wavelength plasmonic structures have recently shown great promise for absorption of energy in the infrared regime due to their high field localization around the plasmonic inclusion. The resulting emission can be dictated through the morphology of the structure. In this work, several plasmonic structure architectures were simulated and characterized in the thermal infrared band for their ability to achieve "by design" control of the spatial component of the emittance pattern. This control produces nulls in the pattern which would prevent unwanted thermal loading from the environment and surrounding spacecraft structures while enabling heat rejection to desirable regions, such as deep space. Represented architectures are metallized gratings, layered thin films, and 2-D and 3-D arrays of absorbers with metallic or dielectric substrates. Morphological considerations, such as the inclusion and host geometries, structure dimension and array periodicity, were analyzed for how they influenced the overall shape of the emittance pattern. The structures were simulated using finite-element and finite-difference time domain methods, with results obtained for both coherent sources (TE/TM plane wave illumination) and incoherent sources (thermal excitation). Directional and hemispherical spectral emittances were calculated from light and dark field spectroscopy, while bulk optical properties were extracted from ellipsometry and x-ray diffraction. Benefits and barriers to application for spacecraft thermal control are discussed.

9085-7, Session 2

Chalcogenide glass thin-film optics for infrared applications in space

Janardan Nath, Deep Panjwani, Douglas Maukonen, Robert E. Peale, Univ. of Central Florida (United States); J. David Musgraves, Peter F. Wachtel, Jennifer M. McKinley, IRradiance Glass, Inc. (United States)

Chalcogenide glasses are increasingly used in infrared systems for space applications due to their relatively low density (compared to Ge or ZnSe), tunable spectral and thermo-mechanical properties, and molding capability. Remaining challenges include their application to thin-film optics and coatings and their potential susceptibility to radiation damage in the space environment. The high refractive indices of chalcogenide glasses (n > 2.7) suggest the possibility for high reflecting (HR) coatings based on few periods of alternating layers with high index contrast. For instance, a quarter wave Bragg stack with 98% reflection in the wavelength range 4.3 - 5.3 microns requires just 5 periods of AsSe glass alternating with Al2O3. Investigation of thin film deposition by thermal or electron-beam evaporation and rf-sputtering, and the measured properties of the resulting HR films, will be discussed. Compositional design of chalcogenide glass substrates for space optics will be presented, together with results of exposure to radiation in near-space at an altitude of 30 km.

9085-8, Session 2

AE9/AP9/SPM: new models for radiation belt and space plasma specification

W. Robert Johnston, Air Force Research Lab. (United States); T. Paul O'Brien, The Aerospace Corp. (United States); Stuart L. Huston, Atmospheric and Environmental Research, Inc. (United States); Gregory P. Ginet, MIT Lincoln Lab. (United States); Timothy B. Guild, The Aerospace Corp. (United States); Judy Fennelly, Air Force Research Lab. (United States)

A new set of models for the flux of particles in the Earth's inner magnetosphere has been developed for use in space system design and other applications requiring a climatological specification. Denoted AE9, AP9, and SPM for energetic electrons, energetic protons and space plasma, respectively, the models comprise 30 independent data sets measured by satellite on-board sensors. These data sets have been processed in a manner to create maps of the particle fluxes together with estimates of uncertainties due to both imperfect measurements and space weather variability. Furthermore, the model architecture permits the Monte-Carlo estimation of the time evolution of fluxes and derived quantities, e.g. the median and 95th percentile, along an arbitrary orbit. An overview of the model will be presented, addressing in particular the latest AE9/AP9 version release.

9085-9, Session 3

A space dual-sensor for Earth flux measurements

Irbah Abdanour, Mustapha Meftah, LATMOS (France)

The Earth's radiation budget was one of the earliest space scientific missions of Earth-orbiting satellites. Since 1960, several space missions were developed for global measurements of the Earth's thermal emission, the solar radiation reflected from Earth and the energy incoming from the Sun.

These space missions require however, significant investments. We have developed a method to achieve Earth flux measurements analyzing the data provided by a simple dual sensor placed on a satellite moving on a Low Earth Sun-synchronous orbit. This sensor allows then the measurements of the outgoing long-wave radiations and the short-wave radiations. This paper presents this model and the results deduced from our analysis. This kind of sensor may be in the future, embedded on nano-satellites taking advantage of this new promising technology.

9085-10, Session 3

Development of a spherical aerial vehicle for lunar exploration

Kang Hou, Hanxu Sun, Qingxuan Jia, Yanheng Zhang, Beijing Univ. of Posts and Telecommunications (China)

SAV (small aerial vehicle) is one of the hottest research fields in robotics because of its low cost, operational environment, and small size. It is a kind of person-portable aircraft which has flexible movement in the relatively small areas. Spherical aerial vehicle is a new and novel kind of small aerial vehicles in the last few years. Compared to other small aerial vehicles, spherical air vehicle has significant advantages due to its special structure. It has a spherical hollow shell to protect the propeller, motor systems, all control circuits, and power supply devices inside. And the spherical shell should be made to result in little loss of rotor system aerodynamic efficiency. Due to the characteristics of its structure, the spherical air vehicle can effectively protect its inner parts with the spherical shell when the vehicle lands on the ground in any posture. In this paper, the spherical aerial vehicle and its aerodynamics model is presented and studied. Firstly, the unique structure and features of spherical aerial vehicle are introduced in detail. And then the aerodynamics theory based on this vehicle's structure is analyzed, and the equations of force and moment acting on the spherical aerial vehicle were deduced. Due to the above analysis, the aerodynamics model based on the unique structure features of spherical aerial vehicle is established and derived to get the relationship between the aircraft physical parameters and the aerodynamics parameters. At last, the simulations and experimental results are provided to confirm the feasibility of the spherical aerial vehicle's aerodynamics theory and model.

In this paper, the dynamic models based on the unique structure features and control characteristics are derived, and the relative control methods for this air vehicleare proposed. First, to complete the six degrees of freedom of movement for spherical aircraft in the air, the aircraft structure and steering direction control system are designed; then, based on the theories of rigid body dynamics and aerodynamics, the dynamics of the spherical aircraft are analyzed, and the equations of force and moment acting on the aircraft were deduced and its dynamic model is established. Based on the above kinetic model, the model of aircraft motion control is established and linearized to get the relationship between the aircraft physical parameters and the dynamic stability. Experiment result shows that the aerodynamic models and control methods is available performance, to facilitate the movement of hovering for spherical aircraft.

9085-11, Session 3

Using sky polarization to localize and navigate in GPS-denied environments

Todd Aycock, Art Lompado, Polaris Sensor Technologies, Inc. (United States)

Localization is critical to navigation functions of autonomous and unmanned vehicles. For most vehicles, roll and pitch are measured accurately through inertial measurement units (IMUs) and altitude is measured accurately with an altimeter. Compasses (or other heading measurement devices) and the Global Positioning System (GPS) are necessary to accurately determine a vehicle's latitude, longitude, and heading. Incidentally, these localization parameters are the most important in many vehicles, particularly land and sea-based platforms. However, accurate absolute heading sensors are expensive and/or unreliable in a number of situations, and GPS can be easily denied or spoofed using inexpensive hardware. Therefore, a different sensing technique which utilizes information not susceptible to these same vulnerabilities is desirable. In this paper, the authors investigate the use of a sky polarization sensor to determine absolute heading in order to enhance or augment navigation capabilities in unmanned vehicle applications.

9085-12, Session 3

Membrane based thermoelectric sensor array for space debris detection

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In this paper we present a newly designed highly sensitive impact detector array with 16 pixels for a space debris and micro-meteoroid detector.

The human made space debris in the low earth orbit becomes more and more an increasing risk for space missions, which includes the total mission loss. For risk analyses and for the development of highly effective shields it is necessary to have a profound knowledge about the properties of these particles like the mass, the velocity and the trajectory.

The thermopile sensor array, which was developed in the project, consists of 16 miniaturized multijunction thermopile sensors made by modern thin-film technology on Si wafers. Each thermopile sensor consists of 100 radially arranged junction pairs formed from evaporated antimony and bismuth thin films. The centrally located active (hot) junctions comprise the active area of 1 mm?. The output e.m.f. of the sensor is proportional to the temperature difference between the active and the reference junctions. The thermopile requires no cooling and no bias voltage or current for operation. It generates no 1/f noise but only the thermal resistance (Nyquist) noise. The sensor can be used for DC and low frequency AC measurements.

The impact energy of micro sized particles is measured by a calorimetric principle. This means that the kinetic energy of the particle is converted into heat by hitting the absorbing foil, which is glued on the surface of the membrane area.

This setup in combination with a preceded velocity detector allows measuring the most interesting particle quantities mass, velocity and trajectory.

9085-13, Session 3

Flight test of a flight-in-flight suborbital payload concept

Gerardo Martinez, Ravshan Rustamov, Armando Munoz, Ou Ma, New Mexico State Univ. (United States)

We have been developing new robotics-based technology for identifying the inertia parameters (mass, mass center location, and moments of inertia) of a spacecraft or satellite in orbit. Test of such technology requires an orbit-like full 3D or 6 DOFs (degrees of freedom), smooth microgravity environment but such an environment is very difficult to obtain in laboratory. The research team tried to test the technology using parabolic flights provided by NASA but the results were not satisfactory because the microgravity condition generated by the parabolic flight was not only too short (about 15~20 seconds) but also non-smooth. Therefore, we proposed to test the technology using suborbital flight which can provide smooth microgravity condition for 200 or more seconds. However, suborbital flight poses new challenges in comparison with the parabolic flight because a suborbital flight experiment must be operated autonomously and the available experimental space within the vehicle is much smaller. To deal with

the new challenges and maximize the mission success, the research team proposed a two-flight approach. The first flight is to test a flight-in-flight payload capability and the second flight is to test the robotics-based inertia identification technology. Obviously, the second flight will be built on the success and experience of the first flight. This paper reports test flight which was just lunched with the Up Aerospace's Spaceloft XL vehicle from the Spaceport America on November 12, 2013. It was a successful flight.

The flight-in-flight payload is a special payload which has a "flying unit" (mimicking a spacecraft or another orbital object) flying or floating within a compartment space of the payload during the microgravity phase of the suborbital flight. Due to the special way a suborbital launch and flight operate, the flight-in-flight payload must have the following basic functions:

1) Secures the flying unit to its base during the launch phase

2) Ejects the tethered flying unit to let it free flying within the compartment of the payload when microgravity occurs

3) Pulls the flying unit back toward its base before the microgravity about to finish;

4) Secure the flying unit to its base for landing

5) Measure and record the motion state of the flying unit throughout the entire flight duration for post-launch analysis.

All of these functions must be performed automatically because no manual operations are allowed in a suborbital flight. The paper will describe the design, the pre-launch tests, and the flight test result of these functions.

9085-14, Session 3

Constrained orbital intercept evasion

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An effective characterization of intercept-evasion confrontations in various space environments and a derivation of corresponding solutions considering a variety of real-world constraints is a daunting theoretical and practical challenge. Current and future space-based platforms have to simultaneously operate as a part of satellite formations and/or systems and at the same time, have a capability to evade potential collisions with other maneuver constrained space objects. In this article, we formulate and numerically approximate solutions of a Low Earth Orbit (LEO) intercept-maneuver problem in terms of game-theoretic capture-evasion guaranteed strategies. The space intercept-evasion approach is based on Liapunov methodology that is already demonstrated on a set of air and ground based multi-player multi-goal game/control applications. The corresponding numerical algorithms are derived using computationally efficient and orbital propagator independent methods that are previously developed for Space Situational Awareness (SSA). This game theoretical but in the same time robust and practical approach is demonstrated on a realistic LEO scenario using existing Two Line Element Sets (TLEs) and Simplified General Perturbation-4 (SGP-4) propagator.

9085-15, Session 3

The art and science of missile defense seeker design

Brian K. McComas, Raytheon Missile Systems (United States)

A Missile Defense Seeker is a complex optical system which sits idle for long periods of time and must work with little or no on-board calibration, be used to find and discriminate targets, and guide the kill vehicle to the target within minutes of launch. This paper will provide a short overview of the Missile Defense problem and will discuss the top level performance drivers (like Noise Equivalent Irradiance (NEI), Acquisition Range, and Dynamic Range) which influence the design of these systems. These top level parameters influence the choice of optical system, mechanical system, focal plane array (FPA), Read Out Integrated Circuit (ROIC), and cryogenic system. This paper will not only discuss the physics behind the performance of the sensor, but it will also discuss the "art" of optimizing the performance of the sensor given the top level performance parameters. The balancing of these Seeker systems is key to their performance in these highly stressful missions. The top level performance requirements impact the choice of lower level hardware and requirements. This paper will discuss the flow down of requirements to the lower level hardware. This flow down directly impact the FPA and careful selection of FPA is required. The flow down influences FPA material choice and cooling requirements. This paper will discuss the key physics behind the detector and cryogenic system interactions and the pit falls for system performance. Finally, the overall system balance and optimization will be discussed in the context of Missile Defense Seekers and expected performance of the overall kill vehicle.

9085-16, Session 3

Study of human arm motion strategy for a robotic capture of a fast moving and/or tumbling object

Lin Zhang, Zheng Wei, Ou Ma, Igor Dolgov, New Mexico State Univ. (United States)

Many orbital objects such as malfunctioning satellites or orbital debris are spinning or tumbling in their orbits. The most risky operation of a satellite on-orbit service (OOS) mission would be the capture of a tumbling satellite. For example, the original planned capture of the slowly spinning Intelsat VI by one astronaut in the Space Shuttle's STS-49 mission not only failed but also caused the satellite to tumble (and thus more difficult to capture thereafter). After a second attempt with two astronauts also failed, NASA had to deploy a record-set 3-astronaut team and worked more than eight hours to finally capture and de-tumble the satellite. Due to the limitations of existing robotics technology, such a challenging task cannot be done by a robotic arm. On the other hand, most future OOS missions will have to be done by robots simply because EVAs are unavailable in most missions, especially in GEO orbits or deep space environments. Therefore, we are highly motivated to develop new technology for reliably capturing tumbling objects in orbit.

When comes to capturing a fast moving and/or rotating object, a human tends to do much better than a robot arm unless the motion trajectory of the object is known to the robot in advance. This inspired us to study human capture behavior, hoping what we learned from human can be applied to a robot to improve its capture skills. We performed a set of human capture tasks and analyzed the 3D test data recorded by a 10-camera motion capture system. The analysis revealed that humans, like many other animals, used a strategy of controlling the time-to-contact (TTC) to approach the moving object for capture. Although different humans tended to have very different arm-approach paths, everyone used the same TTC strategy that was: closing the gap between the approaching hand and the object following the same exponential time function. This is consistent with what has been discovered by biologists from observing the approach-and-capture behavior of many animals, which is known as the Tau principle. What we have found was that the original Tau model is a simplified linear form of a more accurate nonlinear model. We are still performing further experimental study to reveal the nonlinear nature of the Tau model. On the other hand, we are conducting a simulation study where our experimentally generated Tau model is applied to a 6-joint manipulator as a guidance strategy to control the robot to reach and catch a fast swing pendulum ball. The dynamic simulation demonstrated that the robot can robustly reach and capture the swing ball even when the swing motion varies from time to time (by changing the mass of the ball and the length of the pendulum string). The paper will describes the study results and also explain how this new technology can be applied to a space robot for capturing a tumbling object in orbit.

9085-17, Session 3

Validation and comparison of two varying subspace-based trajectory optimization methods in a vision-based ground robot testbed

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Trajectory planning is an important topic in the area of autonomous robot research; however, finding an optimal trajectory considering dynamic constraints is still challenging. A bio-inspired varying manifold method has been investigated recently to solve this type of problem.

A vision-based robot testbed is recently designed, developed, and used to test new optimal trajectory planning optimization. The positions of obstacles and robots are located using a webcam hanging on the ceiling of the testbed. The test settings are random generated, including the initial and final position of robots, and the distribution of obstacles. The CPU computational times and arrival times are recorded and compared in each case. Two recently developed methods, based on the "local pursuit" and "motion camouflage" predator-prey relations are tested. It is shown that (1) both methods can generate feasible obstacle free trajectories with a high success rate; and (2) the success rate in finding optimal solutions using the local pursuit inspired method is relatively higher than that of the motion camouflage inspired method.

9085-18, Session 4

SecureCPS: preventing attacks on a nanosatellite propulsion system

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Maneuvering thrusters have traditionally allowed large satellites to dramatically increase the range of missions they can accomplish. Now, inexpensive nanosatellite designs plan to employ maneuvering thrusters for similar purposes. Unfortunately, if their command and control system is compromised, even the smallest nanosatellite can become a threat to space-based High-Value Assets (HVA). Securing nanosatellites which require a maneuvering capability is challenging due to extreme cost, size, and power constraints inherent in a nanosatellite design. However, because a nanosatellite can threaten an HVA, it must provide a level of security typically reserved for an HVA, at least for the functionality of a nanosatellite that might threaten an HVA.

Similar problems are prevalent in many other systems that combine propulsion systems and computer control, such as automobiles, trains, and aircraft. As a result, providing a low-cost architecture to secure a nanosatellite propulsion system against cyber attack, would also benefit a broad class of cyber-physical systems (CPS).

For this research we focus on the ARAPAIMA nanosatellite architecture. We also assume any off-the-shelf component used in ARAPAIMA could be compromised (e.g., supply chain attack). Based on these assumptions, we analyze how attacks can propagate in the ARAPAIMA architecture. The systematic approach used for this analysis is presented along with the Cyber-Physical Attack Description Language (CP-ADL) used to describe the attack scenarios.

The SecureCPS architecture we propose to secure ARAPAIMA is divided into three main components. First, a low-cost radiation hardened trusted module provides the "root of trust" from which all trusted operations derive their approval to operate. In this paper we describe the properties of this module. Second, we extend security from the trusted module into the ARAPAIMA architecture using Global InfoTek Inc.'s Automated Malware Analysis System (GAMAS). GAMAS validates each binary prior to execution using a low-level driver and library of known-good checksums. GAMAS also provides low-level instrumentation to support our machine learning component. To ensure GAMAS can be trusted, each instance is validated by the trusted module on a recurring basis. Third, past history shows known good software can perform malicious actions, so we employ machine learning to learn models of normal behavior on the ground, so we can identify abnormal behavior in orbit. This paper describes the SecureCPS architecture, the individual components of SecureCPS, and how CP-ADL will support scenario-based testing of the entire SecureCPS system.

9085-19, Session 4

A resilient and secure software platform and architecture for distributed spacecraft

Abhishek Dubey, Gabor Karsai, William Otte, Vanderbilt Univ. (United States)

A fractionated spacecraft is a cluster of independent satellite modules flying in formation that communicate via ad-hoc wireless networks. This system in space is a 'cloud platform' that facilitates sharing sensors and other computing and communication resources across multiple applications, potentially developed and maintained by different organizations. Effectively, such architecture can realize the functions of monolithic satellites at a reduced cost and with improved adaptivity and robustness.

Such space-based sensor architectures pose unique challenges to software developers because of the highly distributed nature of the applications, the resource constraints, and the dynamic network. These problems are compounded if the goal is to provide an open, distributed computing platform that runs applications from different security domains and organizations, and where information flows have to be carefully managed and compartmentalized. If the platform is used as a robust shared resource its management, configuration, and resilience becomes a challenge in itself.

To address these requirements, our team has designed and prototyped a novel software platform. The core element of the platform is a new operating system whose services were designed to restrict access to the network and the file system, and to enforce resource management constraints for all non-privileged processes. Mixed-criticality applications operating at different security labels are deployed and controlled by a privileged management process that is also pre-configuring all information flows. Resource constraints are addressed by strict temporal and spatial partitioning and a resource quota system, while access to physical resources, including payload modules, is controlled by multi-level security policies.

9085-20, Session 4

Cyber threat impact assessment and analysis for space vehicle architectures

Robert M. McGraw, RAM Labs. (United States)

This paper covers research into an assessment of potential impacts and techniques to detect and mitigate cyber attacks that affect the networks and control systems of space vehicles. Such systems, if subverted by malicious insiders, external hackers and/or supply chain threats, can be controlled in a manner to cause physical damage to the space platforms. Similar attacks on Earth-borne supervisory control and data acquisition (SCADA) or control systems include the Shamoon, Duqu, Flame and Stuxnet viruses. These have been used to bring down foreign power generation and refining systems. This paper will discuss the potential impacts of similar cyber attacks on space-based platforms through the use of simulation models, including custom models developed in Python using SimPy and commercial SATCOM analysis tools such as STK/SOLIS.

The paper will discuss the architecture and fidelity of the simulation model that has been developed for performing the impact assessment. The paper will go on to walk through the application of an attack vector at the subsystem level and how it affects the control and orientation of the space vehicle. SimPy will be used to model and extract raw impact data at the subsystem sensor level, while STK/SOLIS will be used to visually display the effect on the physical plant of the space vehicle.

The paper will go on to discuss mitigation methods, including a Cyber Physical Sentry (CP Sentry) solution being developed by RAM Laboratories and Auburn University. This solution continuously monitors and assesses subsystem sensor and internal state metrics while detecting anomalous behavior consistent with the execution of the attack vector.

9085-21, Session 4

Building space operations resiliency with a multi-tier mission architecture

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A variety of naturally occurring (e.g., solar activity) and other (e.g., deliberate attack, residual space object impact) risk factors exist for orbital assets. While some risk sources are predictable (e.g., via solar activity projection, object tracking) others can occur without notice (e.g., anti-satellite attack, impact by piece of space junk below the tracking threshold). Resiliency to these types of perils can be created via spacecraft hardening or redundancy. While hardening can prevent certain levels and forms of some known risk sources, it is not a complete solution. Redundancy, conversely, may result in additional cost from hardware that is not needed (or of limited additional value) until an event occurs. A "tier scalable" exploration architecture has been proposed by Fink and previous expanded upon. The utility of a multi-tier mission/operations architecture as a resiliency solution for a variety of sensing needs is now considered.

This paper provides an overview of multiple different risk sources to spacecraft. It then provides an overview of the multi-tier mission/operations architecture. The various types of craft that can participate (both those considered by previous work and other possible types) are discussed as are prospective deployment patterns. Next, a mission plan for a high-resiliency sensing mission is presented and evaluated. This plan focuses on a sensing mission with a particular detection target, where aerial and ground craft are deployed based on the identification of factors likely to mean that the object of interest is present in the region. Finally, the paper concludes by considering next steps for testing this designed-for-resilience multi-tier architecture.

9085-22, Session 4

An adaptive process-based cloud infrastructure for space situational awareness applications

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Space situational awareness (SSA) and defense space control capabilities are top priorities for groups that own or operate man-made spacecraft. Given the growing amount of space debris, there is an increase in demand for contextual understanding that necessitates the capability of collecting and processing a vast amount sensor data. Cloud computing, which features scalable and flexible storage and computing services, has been recognized as an ideal candidate that can meet the large data contextual challenges as needed by SSA. Cloud computing consists of physical service providers and middleware virtual machines together with infrastructure, platform, and software as service (IaaS, PaaS, SaaS) models. However, the typical Virtual Machine (VM) abstraction is on a per operating systems basis, which is at too low-level and limits the flexibility of the mission application architecture. In responding to this technical challenge, a novel adaptive process based cloud infrastructure for SSA applications is proposed in this paper. In addition, the design rationales are introduced in details and a prototype is further examined. This conceptual capability will potentially support space situation monitoring and tracking, object identification, and threat assessment. Lastly, the benefits of a more granular and flexible cloud computing resources allocation are illustrated for data processing and implementation considerations within a representative SSA system environment.

9085-23, Session 4

Securing resource constraints embedded devices using elliptic curve cryptography

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The use of smart embedded device has been growing rapidly in recent time because of miniaturization of sensors and platforms. Securing data from these embedded devices is now become one of the core challenges both in industry and research community. Being embedded, these devices have tight constraints on resources such as power, computation, memory, etc. Hence it is very difficult to implement traditional public key encryption into these resource constraint embedded devices. Identity Based Encryption (IBE) is a form of asymmetric cryptography like RSA (Rivest-Shamir-Adleman). However, unlike RSA which requires both public and private key to be generated together, IBE allows a public key to be generated from an arbitrary string and that the private key is generated later on demand. While IBE has been actively studied and widely applied in cryptography research, conventional IBE primitives are also computationally demanding and cannot be efficiently implemented on embedded device. Simplified version of the identity based encryption (IBE-Lite) has proven its competence being robust and also satisfying tight budget of the resources. In this paper, we described the choice of several parameters in the IBE-Lite scheme, and the implementation of the encryption in an embedded sensor node. Our implementation of IBE-Lite is built upon elliptic curve cryptography (ECC), a public key primitive suitable for resource constraint embedded system.

9085-24, Session 5

Toward QoS provisioning for layered network communications

Wei Yu, Guobin Xu, Sixiao Wei, Towson Univ. (United States); Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Khanh Pham, Erik Blasch, Air Force Research Lab. (United States); Chao Lu, Towson Univ. (United States)

Layered network communications can not only provide a global coverage for various mobile devices but also render multimedia and data services for end users. In this paper, we develop a 3D space Mobile Ad Hoc Network (MANET) architecture that consists of mobile hosts, terrestrial base stations, manned fast movers, unmanned aerial vehicles, airborne relays, and space vehicles, in which mobile nodes within each other's radio range can communicate directly through wireless communication links. To achieve QoS guarantee to various applications and operational needs, we present an innovative software communications architecture, namely a Service-Oriented Architecture (SOA) that consists of three layers: service, control, and network layers and develop efficient and secure service-oriented provisioning schemes. Through a combination of theoretical analysis and simulation studies, we evaluate the effectiveness of our proposed architecture and service-oriented provisioning schemes for reconfigurability, easy-to-upgrade design, and so on.

9085-25, Session 5

Dynamic autonomous routing technology for IP-based satellite ad hoc networks

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IP-based routing for military LEO/MEO satellite ad hoc networks is very challenging due to network and traffic heterogeneity, network topology and traffic dynamics. In this paper, we describe a traffic priority-aware routing scheme for such networks, namely Dynamic Autonomous Routing Technology (DART) for satellite ad hoc networks. DART has a cross-layer design, and conducts routing and resource reservation concurrently for optimal performance in the fluid but predictable satellite ad hoc networks. DART ensures end-to-end data delivery with QoS assurances by only choosing routing paths that have sufficient resources, supporting different packet priority levels. In order to do so, DART incorporates several resource management and innovative routing mechanisms, which dynamically adapt to best fit the prevailing conditions. In particular, DART integrates a resource reservation mechanism to reserve network bandwidth resources; a proactive routing mechanism to set up non-overlapping spanning trees to segregate high priority traffic flows from lower priority flows so that the high priority flows don't face contention from low priority flows; a reactive routing mechanism to arbitrate resources between various traffic priorities when needed; a predictive routing mechanism to set up predictive routes for scheduled missions and for anticipated topology changes for QoS assurance. We present simulation results showing the performance of DART. We have conducted these simulations using the Iridium constellation and trajectories as well as realistic military communications scenarios. The simulation results demonstrate DART's ability to discriminate between high-priority and low-priority traffic flows and ensure disparate QoS requirements of these traffic flows.

9085-26, Session 5

Toward effectiveness and agility of network security situation awareness

Wei Yu, Linqiang Ge, Towson Univ. (United States); Dan Shen, Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Khanh Pham, Air Force Research Lab. (United States); Erik Blasch, Intelligent Fusion Technology, Inc. (United States); Chao Lu, Towson Univ. (United States)

Defending against cyber threats calls for network security situation awareness (SA) through distributed collaborative monitoring, detection, and mitigation. Specifically, effective allocation of defense resources to detect threats while the adversary tries to learn the network and security polices has been proven to be one of major R&D milestones for network resiliency. In this direction, defense system deployment knowledge is critical. Here we develop a modeling framework to investigate tradeoffs between threat detectability, system risk, and defense deployment cost. In addition, we also develop a moving target defense scheme that can effectively adapt system components based on security risk assessment to actively change the system and render attacks ineffective. Through a combination of theoretical analysis and performance studies, we validate our developed model to mitigate attacks through measures of effectiveness of our proposed schemes.

9085-27, Session 5

Crosstalk-immune fiber optic sensor based on wavelength-division-multiplexing employing the frequency spectral ratio method for disturbance detection and location

Yuan Wu, Pang Bian, Bo Jia, Qian Xiao, Fudan Univ. (China)

A novel fiber optic sensor immune to the crosstalk of the wavelength-division-multiplexing employing frequency spectral ratio method for distributed detection and location is proposed and demonstrated. The sensor employs a hybrid configuration of Mach-Zahnder and Sagnac interferometer as interfering unit. A broadband, low-coherence source is spectrally sliced into two wavelength bands using wavelength division multiplexer. Therefore, the sensor consists of two interferometers, multiplexed with a broadband light source, interfering unit and sensing loop by wavelength division multiplexer. Two piezoelectric transducer (PZT) phase modulators, modulated at frequencies , , are connected at the two end of the sensing loop and hence four modulated desired signals with two different wavelengths are obtained, whereas the baseband cross-talk lights can be removed by the filters based on the frequency difference between the desired signals and cross-talk lights. Hence four detected signals with two different wavelengths are obtained. After the demodulation scheme based on 3?3 coupler, two phase shifts caused by the disturbance are achieved and fast Fourier transform are performed on the phased shifts, and hence the location of the disturbance gained by the frequency spectrum ratio method enables the localization comparably accurate. Experimental results show that the sensor is especially advantageous for low location error to the application of intrusion detecting.

9085-28, Session 6

Quantum technology in aerospace applications

Bin Jia, Intelligent Fusion Technology, Inc. (United States); Khanh Pham, Air Force Research Lab. (United States); Genshe Chen, Dan Shen, Zhonghai Wang, Intelligent Fusion Technology, Inc. (United States)

The quantum technology will fundamentally change the world. In this presentation, the quantum technology and its applications in aerospace, such as quantum computing, quantum control, and quantum communication, are introduced. As expected, a cognitive measurement method using information-theoretic learning criteria based on entropy is proposed to facilitate feedback control synthesis of adaptive quantum systems. Potential contributions to aerospace applications of quantum technology, including quantum space communications with resiliency and robustness are also discussed.

9085-29, Session 6

Polarization tracking for quantum satellite communications

Gang Wang, Dan Shen, Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Khanh Pham, Erik Blasch, Air Force Research Lab. (United States)

Satellite networks and quantum communications offer complementary opportunities for enhanced operations. Quantum communications provide security for the transmissions between satellites and ground stations; while the free-space link of satellite networks provide the potential of long distance transmission of quantum bits (qubit) for space communications. However, with the promising advantages, challenges remain to fully develop quantum-based satellite communictans such as robust reliable information detection which is difficult due to the movement of satellites. In this paper, a polarization tracking algorithm is proposed for polarization-encoded

quantum satellite communications. The polarization tracking is essential for the decoding of a qubit and the quantum key distribution (QKD). A channel model for free-space quantum communications is adopted and developed in this paper. With the estimated polarization, a novel dynamic polarization compensation scheme is also proposed. The results show that our methods can accurately estimate the polarization, then providing much lower quantum bit error rate (QBER) by compensation, as compared with the direct qubit detection without polarization tracking and compensation.

9085-30, Session 6

Quantum-entanglement-based QKD security guarantee over QoS-driven 3D satellite networks

Ping Wang, Xi Zhang, Texas A&M Univ. (United States); Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

Security guarantee is one of the most important requirements in military communications. Quantum key distribution (QKD) is a methodology for generating and distributing random encryption keys using the principles of quantum physics, which enables two distant communications parties to securely communicate in a way that cannot be eavesdropped on without being detected. In particular, QKD technologies seek to provide reliable, efficient security for wireless links between the ground station and the satellite employed in military communications under tactical and strategic environments. We propose a Quantum-Entanglement based QKD security scheme to obtain the absolute security while guaranteeing the QoS (quality of service) of the transmission information, considering the link attenuation including the effect of beam diffraction, attenuation, and turbulence-induced beam spreading caused by the atmosphere, receive aperture diameter, losses within the telescopes acting as antennas, as well as antenna pointing loss. The simulation results show that our proposed Quantum-Entanglement security scheme based on the QKD technologies offers many advantages for secure data transmission between the satellites and ground stations, in terms of reliable and high-data-rate transmission requirements.

9085-31, Session 7

Resident space object tracking using an interacting multiple model mixing scheme

Quang M. Lam, LexerdTek Corp. (United States)

A multiple model estimation scheme is proposed to enhance the robustness of a resident space object (RSO) tracker subject to its maneuverability uncertainties (unplanned or unknown jet firing activities) and other system variations. The concept is based on the Interacting Multiple Model (IMM) estimation scheme. Within the IMM framework, two Extended Kalman Filter (EKF) models: (i) a 6 State (Position and Velocity of a constant orbiting RSO) EKF and (ii) a 9 state (Position, Velocity, and Acceleration of a maneuvering RSO) EKF are designed and implemented to achieve RSO maneuvering detection and enhanced tracking accuracy. The IMM estimation scheme is capable of providing enhanced state vector estimation accuracy and consistent prediction of the RSO maneuvering status, thus offering an attractive design feature for future Space Situational Awareness (SSA) missions. The design concept is illustrated using the Matlab/Based Simulation testing environment.

9085-32, Session 7

Orbit determination accuracy enhancement from image data using random finite set based filters

Quang M. Lam, LexerdTek Corp. (United States); Ba-Ngu B. Vo, Curtin Univ. (Australia)

Determining orbits of uncorrelated targets (UCTs) is a fundamental Space Situational Awareness (SSA) activity. The U.S. Space Surveillance Network (SSN) currently relies on ground-based radars, optical telescopes, and the Space Based Space Surveillance (SBSS) System. The SBSS system overcomes many of the pitfalls of optical ground-based systems like limited observation times (e.g. weather and time of day) and measurement uncertainty from atmospheric effects. However, the SBSS satellite is in a low earth orbit (630 km, sun synchronous), and must look “up” for GEO objects. This paper investigates the potential benefits of a GEO based optical sensor deployed using a hosted payload path or low cost nanosat platform for performing metric observations that can be combined with ground-based data to further enhance the UCTs detection and tracking. Several different scenarios are considered to quantify the reduction in orbit uncertainty from these angle only observations (i.e., azimuth and elevation angles measurements) using both angle only Extended Kalman Filter (EKF) and Random Finite Set (RFS) Based Filter (e.g., Probability Hypothesis Density Filter via Sequential Monte Carlos implementation). The primary objective of this investigation is threefold: (1) relax the Initial Orbit Determination (IOD) accuracy via the Gauss Based Approach for the EKF initialization to begin its sequential processing; (2) leverage the front end measurement to track association free step of the RFS based filter to efficiently determine a new SSA processing scheme to benefit the UCTs resolution; and (3) Determine the feasibility of using the 2-D (Azimuth-Elevation Angles Window) image to benefit the 3-D Orbit Position and Velocity Reconstruction. Simulation based evaluation will be conducted to complete the investigation.

9085-33, Session 7

Space object surveillance using incidental measurements from vehicle-board sensors

Sandip Roy, Washington State Univ. (United States)

As orbital space becomes increasingly cluttered and multi-playered, there is a growing need for surveillance of space objects. Based on this motivation, numerous studies on space-object surveillance have been advanced in recent years, which focus on such diverse tasks as target detection and tracking, anomaly detection, adversary pursuit, and mission-level sensor scheduling for surveillance. Largely, these studies of space surveillance have envisioned technologies that are dedicated to sensing and surveillance. However, future space vehicles will likely be tasked with increasingly diverse and multi-faceted missions including mixed civilian/military functionalities, wherein sensing and surveillance goals are often secondary to other requirements (e.g., transfer of goods or passengers, data communication, commerce). If this paradigm change comes to fruition, space surveillance may depend on incidental measurements from a large number of stochastic mobile vehicles, rather than dedicated measurements from a small number of schedulable sensors.

Here, we formulate and provide initial results on the problem of space object surveillance from incidental measurements. Specifically, we consider surveillance using sensor measurements from a mobile space vehicle, whose stochastic mobility pattern is incidental to the surveillance task. We frame the surveillance problem as an estimation or detection problem for a linear dynamical system with a stochastically-time-varying observation matrix (which reflects the vehicle’s mobility). Under broad conditions on the stochastic observation model, we are able to determine whether or not estimation/detection is possible, and to characterize the estimation or detection performance. In support of these analytical studies, we also develop a simulation example on target tracking from an incidentally-mobile vehicle. Broadly, our analyses and simulations demonstrate that incidental measurements can permit surprising robust, though slower, surveillance of space objects.

9085-34, Session 7

A nanosatellite for study the Sun and the Earth

Mustapha Meftah, LATMOS (France)

Since the launch of the first artificial satellite in 1957, more than 6,000 satellites have been sent into space. Despite technological advances, the spatial domain remains little accessible. However, with the miniaturization

of electronic components, it has recently become possible to develop a small satellite where scientific goals can be achieved. Micro-satellites have demonstrated that these goals were achievable. However, completion times remain long. Today, we hope through the use of nano-satellites to reduce the size, the costs, and the time of development and we wish to increase the accessibility into space for scientific objectives. Nano-satellites have become important tools for space development and utilization, which may lead to new ways of space exploration. This paper is intended to present a future space mission enabled by the development of nano-satellites and the underlying technologies they employ. Our future mission expands observations of the Sun (total solar irradiance measurements) and of the Earth (outgoing long-wave and short-wave radiation measurements). Constellations of nano-satellites to provide simultaneous collection of data over a wide area of geo-space could be built latter and presents a great interest in the context of the Sun-Earth relationships.

9085-35, Session 7

Dexterous and expedient approach strategies considering non-zero eccentricity orbits and J2 perturbations

Charles Remeikas, Yunjun Xu, Univ. of Central Florida (United States); Khanh Pham, Air Force Research Lab. (United States); Genshe Chen, Bin Jia, Dan Shen, Intelligent Fusion Technology, Inc. (United States)

Recently bio-inspired rendezvous strategies have been investigated for applications in space situation awareness. Particularly, closed-loop solutions were developed for the cases where the space object is in a circular orbit without considering any orbital perturbations. In this paper, the dexterous and expedient motions with minimum-fuel consumption considerations are further studied. The case studies considering the J2 perturbation, the non-zero eccentricities, and different boundary conditions are analyzed: (1) the space object is at the local vertical local horizontal coordinate origin; (2) the space object is moving in the local vertical local horizontal coordinate; (3) the rendezvous object approaches the space object from the R-bar, V-bar, and Z-bar directions, respectively. Fast solutions can be obtained for the rendezvous object to approach the space object with minimum energy consumption. It is shown that (1) the fuel consumption is too high for arbitrary orbit transfers from LEO to GEO using this type of dexterous and expedient paths; (2) the dexterous, expedient and free-flying (i.e. no propulsion) path cannot be achieved along the R-bar and V-bar direction; (3) the dexterous, expedient and free-flying path can be obtained along the Z-bar direction.

9085-36, Session 7

Low-complexity image compression with scalable quality control

Bruce H. Pillman, Michael E. Napoli, Exelis Geospatial Systems (United States)

The RICE algorithm is a successful standard for numerically lossless image compression, especially for space applications as described by the Consultative Committee for Space Data Systems in the recommended standard CCSDS 121.0-B-2. It is remarkably simple and adaptable, lightweight, and delivers effective compression for a wide range of signals. The present paper discusses work exploring several additions to the standard RICE algorithm to support lossy compression. In particular, the extended system allows compression to be scaled gracefully from numerically lossless to visually lossy while expanding the visually lossless domain to lower bit rates than are achievable with simple linear quantization approaches. The extended system is slightly more complex than the baseline numerically lossless system, while supporting user adjustment of the quality level to balance quality and bandwidth usage.

9085-37, Session 7

Integrating modeling, test case generation and analysis tools for critical software testing

Nandamudi L. Vijaykumar, Érica F. Souza, Valdivino A. Santiago Jr., Instituto Nacional de Pesquisas Espaciais (Brazil)

Activities of Software Testing becomes increasingly important in software engineering , as they are essential activities in the software development to ensure the quality . There is also a large increase in research on modeling techniques for generating test cases . This work has two main objectives. The first is through a case study to show the integration of a modeling tool and test case generation tool. The modeling tool generates a state machine (FSM) from the representation of the software specification in Statecharts. The test case generation tool generates test cases using the Switch Cover from FSM. The second objective is to show the application of a coverage tool to verify whether the test cases generated, in fact, cover the FSM. The test cases were implemented in Java using JUnit testing tool. Results showed that the proposed solution for the integration of tools with JUnit and subsequent coverage analysis tool enables application of critical software. Modeling tool is PerformCharts, originally developed to specify performance models in Statecharts and evaluate their performance using Markov Chains. This tool has been adapted to also generate test cases when a software can be specified in Statecharts. The second tool implements Switch Cover method to generate test cases from the resulting FSM from the previous tool. Finally, EMMA is the tool that is used to evaluate the coverage of the obtained test suite.

Thursday 8 –8 May 2014

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9086-1, Session 1

Night-vision goggle stimulation using LCoS and DLP projection technology, which is better?

Masoud H Ali, Paul Lyon, Sondre Fauskanger, Barco, Inc. (United States)

High fidelity night-vision training has become important for many of the simulation systems being procured today. The end-users of these simulation training systems prefer using their actual night-vision goggle (NVG) headsets. This requires that the visual display system stimulate the NVGs in a realistic way. Historically NVG stimulation was done with cathode-ray tube (CRT) projectors. However this technology became obsolete and in recent years training simulators do NVG stimulation with laser, LCoS and DLP projectors. The LCoS and DLP projection technologies have emerged as the preferred approach for stimulation NVGs.

Both LCoS and DLP technologies have advantages and disadvantages for stimulating NVGs. LCoS projectors can have 5-10 times the contrast capability of DLP projectors. The larger the difference between the projected black level and the brightest object in a scene, the better the NVG stimulation effects can be. This is an advantage of LCoS technology, especially when the proper NVG wavelengths are used. Single-chip DLP projectors, even though they have much reduced contrast compared to LCoS projectors, can use LED illuminators in a sequential red-green-blue fashion to create a projected image. It is straight forward to add an extra infrared (NVG wavelength) LED into this sequential chain of LED illumination. The content of this NVG channel can be independent of the visible scene which allows effects to be added that can compensate for the lack of contrast inherent in a DLP device.

This paper will expand on the differences between LCoS and DLP projectors for stimulating NVGs and summarize the benefits of both in night-vision simulation training systems.

9086-2, Session 1

A display system luminance requirement that meets user expectations *(Invited Paper)*

Charles J. Lloyd, Visual Performance, LLC (United States)

When digital projectors (i.e., LCD and DLP) began replacing CRT projectors in the simulation training industry circa 2005, most suppliers proclaimed enthusiastically that significantly higher display luminance levels would be obtained using these arc lamp-based devices. While the new technology is clearly capable of producing much higher display luminance levels, users have often found that their systems cannot meet the luminance requirement after only a few weeks or months of operation, and that they have to change lamps more often than expected. This paper provides a quantitative analysis of the design factors that mediate this common failure mode for modern multi-projector display systems. Results of the analysis indicate that primary challenges to actualizing the luminance requirement include the failure to account for factors such as lamp lumen maintenance (lamp life), lamp-to-lamp variation, and the effects of white point and uniformity corrections. Examination of recent requirements documents for simulation trainers revealed that system luminance requirements typically do not address these factors. Unfortunately, any supplier who would identify and account for these factors in their proposal would be disadvantaged relative to other suppliers competing for the contract. This paper provides a simple remedy to this challenge by providing a comprehensive and defensible system luminance requirement and an explicit method of measuring multi-channel display systems to determine conformance with the requirement. This method overtly accounts for the fall off in luminance of arc lamps as they age, thus, both customer and supplier expectations are more appropriately determined at the proposal and acceptance testing phases of an acquisition. The use of this draft metric and measurement method is expected to increase the probability that customers will receive display systems that meet their expectations, and to reduce the disruption to acquisitions caused by arguments over system luminance.

9086-3, Session 1

Focusing the research agenda for simulation training visual requirements

Charles J. Lloyd, Visual Performance, LLC (United States)

Advances in the capabilities of the display-related technologies that could be employed in simulation training devices continue to occur at a rapid pace. Simultaneously, ongoing reductions in defense spending are stimulating the services to push a higher proportion of training into ground based simulators in order to reduce their operational costs. These two trends are causing customer expectations and desires for more capable training devices to increase while the money available for these devices decreases. Thus, there is an increased need to improve the efficiency of the acquisition process and to increase the probability that users will get the training devices they need at the lowest practical cost. In support of this need the IDEAS program was initiated in 2010 with the goal of improving those display system requirements that are associated with disrupted acquisitions and unmet user needs and expectations. This paper describes a process by which the display requirements associated with these challenges are identified, described, and rated so that defensible recommendations for future research can be prepared. Analyses of existing requirements documents revealed that between 40 and 50 specific design parameters (i.e., resolution, contrast, luminance, field of view, frame rate, etc.) are typically called out for the acquisition of a simulation training display system. Clearly, no research effort can address the effects of this many parameters, thus, a defensible strategy for focusing limited R&D resources on a fraction of these parameters was developed. Six criteria are described that were used to identify the parameters most worthy of research attention: Likelihood of disrupted acquisitions, Effect on task performance, Effect on system cost, Measurement error, Measurement cost, and Cost of study. The use of these selection criteria is illustrated by applying the criteria to a dozen candidate design parameters that were recommended for consideration by stakeholders.

9086-4, Session 2

Subjective evaluations of multiple three-dimensional displays by a stereo-deficient viewer: an interesting case study *(Invited Paper)*

John P. McIntire, Sharon A. Ellis, Air Force Research Lab. (United States); Lawrence K. Harrington, Ball Aerospace & Technologies Corp. (United States); Paul R. Havig II, Air Force Research Lab. (United States)

A study was conducted with sixteen observers evaluating four different three-dimensional (3D) displays for usability, quality, and physical comfort. One volumetric display and three different stereoscopic displays were tested. The observers completed several different types of questionnaires before, during and after each test session. All observers were tested for distance acuity, color vision, and stereoscopic acuity. One observer in particular appeared to have either degraded or absent binocular vision on the stereo acuity test. During the subjective portions of the data collection, this observer showed no obvious signs of depth perception problems and finished the study with no issues reported. Upon further post-hoc stereovision testing of this observer, we discovered that he essentially failed all tests requiring depth judgments of fine disparity and

had at best only gross levels of stereoscopic vision (failed all administered stereoacuity threshold tests, testing up to about 800 arc sec of disparity). When questioned about this, the stereo-deficiency was unknown to the observer, who reported having seen several stereoscopic 3D movies (and enjoyed the 3D experiences). Interestingly, we had collected subjective reports about the quality of three-dimensional imagery across multiple stereoscopic displays from a person with deficient stereo-vision. We discuss the participant's unique pattern of results and compare and contrast these results with the other stereo-normal participants. The implications for subjective measurements on stereoscopic three-dimensional displays and for subjective display measurement in general are considered.

9086-5, Session 2

Recent developments in stereoscopic and holographic 3D display technologies

Kalluri R. Sarma, Honeywell Technology (United States)

Significant progress has been made in the stereoscopic and holographic 3D display technologies in recent times for application to defense as well as civilian applications including medical, scientific visualization, industrial, education, and entertainment. In this paper we will review the attributes of these display technologies and then discuss the recent developments in these technologies towards realizing their full potential.

9086-6, Session 3

Light sources for enhanced vision *(Invited Paper)*

Gary W. Jones, NanoQuantum Sciences, Inc. (United States)

A new era of customized light spectra has been enabled by advances in solid state lighting (SSL). Previous methodologies for assessment of quality, intensity, and suitability of specific light sources need to be reconsidered for many applications. Many light sources are still measured against black body radiation references, but this approach is inappropriate for non-blackbody radiators like SSL, such as many types of LED luminaires.

"Lumens" is an intensity metric convolved with the weighted average of an example human eye sensitivity. Most people can perceive light at wavelengths well outside of the established "visible light spectrum", so near-zero lumens may be recorded for light that is perfectly visible. A high color rendering index (CRI) is associated with good color reproduction, but a high CRI does not insure suitability for many applications where probable objects of interest primarily reflect violet or deep-red light. Reassessment of these and other metrics for many applications is essential.

Illumination using reference spectra such as "sunlight-spectrum" are generally useful for color printing comparisons, but a wide distribution of individual eye sensitivities to short and long wavelength light still exists. SSL can be designed to mimic other common light sources, but is this the correct approach for all or even most situations?

What light spectra and intensity may be best suited for optimal visual acuity and the direct-visual detection and identification of the widest range of objects of interest?

How might example alternate lighting spectra integrate with typical digital imagers and display systems?

Well-known specialty LED lighting examples include blood tracking lights for hunters that make fresh blood is easier to identify relative to most outdoor backgrounds, and high red content lighting for enhanced retail displays of meat and bakery goods.

Is a soldier's typical off-the-shelf tactical lighting really the most appropriate for an intended operation? What are the appropriate portable lighting parameters to consider?

Broad spectrum and customized light sources were used to experimentally illuminate various objects to assess suitable lighting spectra for visual detection and identification. Reflected and emitted spectral data obtained by illumination of example objects will be compared, along with a discussion of the aptness of various metrics.

9086-7, Session 3

ARINC 818 specification revisions enable new avionics architectures *(Invited Paper)*

Tim Keller, Great River Technology, Inc. (United States)

ARINC 818, titled Avionics Digital Video Bus, is the standard for cockpit video that has gained wide acceptance in both the commercial and military cockpits including the Boeing 787, the A350XWB, the A400M, the KC-46A and many other aircraft. The ARINC 818 specification that was initially release in 2006 has recently undergone a major update to address new avionics architectures and capabilities. Over the seven years since its release, projects have gone beyond the specification due to the complexity of new architectures and desired capabilities, such as video switching, bi-directional communication, data-only paths and camera and sensor control provisions. The ARINC 818 specification was revised in 2013 was ARINC 818-2 was approved in November 2013.

The revisions to the ARINC 818-2 specification include: switching, stereo and 3-D provisions, color sequential implementations, regions of interest, bi-directional communication, higher link rates, data-only transmission, synchronization signals and optical interface details. This paper discusses each of the new capabilities and the impact on avionics and display architectures, especially when integrating large area displays, stereoscopic displays, multiple displays, and systems that include a large number of sensors.

9086-8, Session 3

Mean performance of the human eye and its implications for display systems

Daniel D. Desjardins, Northrop Grumman Corp. (United States)

This paper proposes to be a comprehensive review of earlier papers by government, industry and university authors regarding performance of the human eye-brain system relative to image size, image resolution (spatial, grayscale, color space, temporal), legibility (luminance and contrast in specified ambient illumination), compatibility with night vision equipment, etc. An understanding as to the background and conditions of these studies shall be given. A summary of the ranges in mean performance for the various parameters shall be reported, with consequent implications as to maximizing ultimate display system design.

9086-9, Session 4

Speckle-free diode laser illumination for the display/projector applications in avionics *(Invited Paper)*

Andrei V Tchernook, NANOLIT GmbH (Germany)

Illumination solutions for avionics are driven by high luminosity, low mass and small dimensions. Today many solutions are based on LEDs which produce substantial excessive heat to achieve the luminosity levels required for daylight displays. LED light is difficult to collimate and/or to shape which results in light losses. Additionally a half of the light is wasted if a display (e.g. LCOS) uses a linearly polarized light.

Diode lasers can be used as an alternative to the LED illumination. Mass and dimensions of the diode lasers are comparable with those of LEDs. They have a substantially higher efficiency compared to LEDs and intrinsically produce polarized light. Output of the diode lasers is simple to shape. Taking into account low requirements of the diode lasers for thermal management they could be a solution of choice for high-end applications where design is mainly driven by performance. The main drawback of the laser diodes for the display/projector purposes is that their output shows a speckle pattern reducing the image quality.

This drawback can be now eliminated through fast phase and/or spatial modulation of the laser beam. Current and potential approaches are analyzed.

A very compact laser illumination concept for LCOS microdisplays is proposed

9086-10, Session 4

Adding intelligence to direct view optical (DVO) sights

Timothy Hogan, Timothy J. Edwards, Kopin Corp. (United States)

The integration of overlay displays into rifle scopes can transform precision Direct View Optical (DVO) sights into intelligent interactive fire-control systems. Overlay displays can provide ballistic solutions within the sight for dramatically improved targeting, can fuse sensor video to extend targeting into nighttime or dirty battlefield conditions, and can overlay complex situational awareness information over the real-world scene. High brightness overlay solutions for dismounted soldier applications have previously been hindered by excessive power consumption, weight and bulk making them unsuitable for man-portable, battery powered applications. This paper describes the advancements and capabilities of a high brightness, ultra-low power text and graphics overlay display module developed specifically for integration into DVO weapon sight applications. Central to the overlay display module was the development of a new general purpose low power graphics controller and dual-path display driver electronics. The graphics controller interface is a simple 2-wire RS-232 serial interface compatible with existing weapon systems such as the IBEAM ballistic computer and the RULR and STORM laser rangefinders. The module features include multiple graphics layers, user configurable fonts and icons, and parameterized vector rendering, making it suitable for general purpose DVO overlay applications. The module is configured for graphics-only operation for daytime use and overlays graphics with video for nighttime applications. The miniature footprint and ultra-low power consumption of the module enables a new generation of intelligent DVO systems and has been implemented for resolutions from VGA to SXGA, in monochrome and color, and in graphics applications with and without sensor video.

9086-11, Session 4

High-brightness displays in integrated weapon sight systems

Timothy J. Edwards, Timothy Hogan, Kopin Corp (United States)

Technology advances over the past several years have resulted in ultra-high brightness microdisplay solutions in VGA, SVGA, SXGA and 2k x 2k display formats. These high brightness display solutions have demonstrated luminance levels greater than 6000fL to the eye and dimming ranges suitable for night viewing compatibility with night vision goggles (NVGs). Highly efficient LED based backlights generate color-specific (white, green, amber, red) illumination providing high luminance levels at power levels compatible with man-portable battery operated applications. This paper will review various approaches for integrating high brightness overlay displays with existing direct view rifle sights and augmenting their precision aiming and targeting capability. Examples of overlay display systems solutions will be presented and discussed. This paper will review significant capability enhancements that are possible when augmenting the real-world as seen through a rifle sight with other soldier system equipment including laser range finders, ballistic computers and sensor systems.

9086-16, Session 4

AMOLED microdisplay automated life time measurement system

Amalkumar P. Ghosh, Ilyas I. Khayrullin, Tariq A. Ali, Ihor Wacyk, Olivier Prache, eMagin Corp (United States)

eMagin has developed and manufactures OLED microdisplays with various resolutions including SVGA+ (852x3x600), SXGA (1280x3x1024), WUXGA (1920x3x1200) and VGA (640x3x480) . A suite of display colors are available including color displays, monochrome white, yellow and green microdisplays. The latter two are ultra-high brightness microdisplays that are currently commercially available. Operational life time is one of the most critically important microdiplay performance parameters. Towards this end, eMagin has designed and built a fully automated life test system that allows one to continuously monitor and measure several characteristics of the displays, including luminance versus time, spectrum and color coordinates simultaneously on multiple microdisplays of various resolutions and driving schemes, i.e. current and voltage driven devices. Various fit algorithms are implemented in the system that allow one to obtain most accurate operational life estimates. Additionally, measuring the life times at various initial luminances allows the determination of acceleration factors for aging the displays. The life test data on eMagin AMOLED microdisplays of various resolutions will be presented. The salient features of the automated life time measurement system will also be presented. 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.

9086-12, Session 5

Advances and trends of head-up displays systems in land vehicles

J. Alejandro Betancur, Gilberto Osorio, Univ. EAFIT (Colombia)

Currently, in the automotive industries the interaction between drivers and augmented reality systems is a topic of analysis, specially the identification of advantages and risks that this kind of interaction represents. This paper attempts to put in evidence the potential of head-up displays systems applied to automotive vehicles, pretending to show applications and tendencies that at the moment are being studied. In general, the automotive advances related to augmented reality devices, suggests the partial integration of the head-up displays in automotive vehicles; however, it is still a matter of discussion how should be the right way to do it.

9086-13, Session 5

Approaches to the design of a low-cost head-up display system

Paul L. Wisely, HOLOEYE Systems Inc. (United Kingdom); Willaim P. Bleha Jr., HOLOEYE Systems Inc. (United States)

Since their inception during the Second World War in the simple reflector gun sights of combat aircraft, HUDs have been developed to achieve ever greater capability and performance, initially in military applications but in the last quarter of the last century for civil applications.

With increased performance and capability came increased complexity and an attendant steady increase in cost such that HUDs in civil applications are only to be found in some large passenger and high end business jets.

The physical volume of current solutions also has a significant impact on where they may be fitted and this paper discusses techniques and approaches to reduce the volume and costs associated with HUD implementation thereby making the operational and safety benefits of HUD available to a broader range of applications in lower value airframes.

9086-14, Session 6

Demosaicing combined video and graphics images from legacy sensors

Ron Christian, Jerome Conway, L-3 Display Systems (United States)

Modern raster display technologies are typically arranged as a Red, Green, Blue (RGB) triad or stripe. Many legacy video sensors, however, originate video in a Red, Green, Green, Blue (RGGB) quadrature arrangement. Video from such sensors may also have computer graphics overlaid before being transmitted to the display. This paper presents a method to demosaic the RGGB combined video and graphics image to the RGB display in real time with excellent reproduction and a minimum of visual artifacts.

Demosaicing algorithms are used to reconstruct a full color image from an incomplete color sampled output, such as a CCD camera overlaid with a Bayer quadrature color filter. Prior demosaicing algorithms are based on two assumptions:

• Spatial Correlation: Pixels within a small region of the image tend to be a similar color, and,

• Spectral Correlation: Red, Green, and Blue components of pixels tend to rise and fall together within a small image region of the image.

These assumptions work well for camera or sensor video, since such video is a representation of the natural, physical environment. These assumptions do not, however, work well for computer-generated graphics overlaid upon the video prior to being received by the display.

The adaptive method presented in this paper demosaics the combined RGGB video and graphics with excellent resolution of the underlying video image, and without false colors or blurring of graphic elements, resulting in the presentation of a higher quality display image to the operator.

9086-15, Session 6

Current state of OLED technology relative to military avionics requirements

Joe Tchon, T. J. Barnidge, Bruce Hufnagel, Birendra Bahadur, Rockwell Collins, Inc. (United States)

The paper will review optical and environmental performance thresholds required for OLED technology to be used on various military platforms. Life study results will be summarized to highlight trends while identifying remaining performance gaps to make this technology viable for future military avionics platforms.

9086-16, Session 7

Is augmented reality ready for prime time: A review of current state-of-the-art and what the future holds

Paul R. Havig II, Air Force Research Lab. (United States); Simon Su, Ball Aerospace & Technologies Corp. (United States); John P. McIntire, Eric E. Geiselman, Air Force Research Lab. (United States)

Augmented reality (AR) has been around for many decades. In fact for the head-mounted display (HMD) community it has been the driving force for implementation of HMDs. AR in an HMD allows one to monitor ownship status while maintaining flight parameters. However, this is not the AR that is most often seen if one searches the literature for AR. In this case AR is usually a see-through HMD with a portable computer giving augmented information about the world to the user (e.g., it tells the user what is inside a building at which they are looking). Recently, Google has announced their Google goggles in which they play on bringing the AR to the everyday user. We discuss both the pros and cons of this potential occurrence and discuss the important human factors considerations that go along with providing such a capability.

9086-17, Session 7

A review of the visual systems of the animal kingdom: Potential for new uses of head-mounted displays

Paul R. Havig II, John P. McIntire, Eric E. Geiselman, Air Force Research Lab. (United States)

Current uses of head-mounted displays (HMDs) are very human-centric. We use them to either present attitude information (e.g., symbology for maintaining flight parameters) or for enhancing our night vision (e.g., a night vision goggle). However, this is the limitation of how they have been used. Current implementations rarely, if ever, present other wavelengths, and they almost never do information fusion. This led us to think about how the rest of the non-human animal kingdom uses the visual sense and if there were any ideas that could be implemented in an HMD. In this paper we review these visual systems and discuss if it is possible and even practical to implement these "ways of seeing" and what benefit they may bring.

9086-18, Session 7

User evaluations of a dichoptic display system

Michael P. Browne, SA Photonics (United States)

No Abstract Available

9086-19, Session 7

The effect of HMD sensor height on platform height estimation

Michael P. Browne, SA Photonics (United States)

No Abstract Available

9086-20, Session 7

Effects of optical combiner in optical see-trough head-mounted display on depth perception

Hong Hua, Jason Kuhn, College of Optical Sciences, The Univ. of Arizona (United States)

A head-mounted-display with an optical combiner may introduce significant amounts of depth distortion to the real world scene. The ability to accurately model the effects of 3-dimensional distortion introduced by thick optical elements has many uses in the development of head-mounted display systems and applications. For instance, the computer rendering system must be able to accurately model this distortion and provide accurate compensation in the virtual path in order to provide a seamless overlay between the virtual and real world scenes. In this paper, we present a ray tracing method that determines the ray shifts and deviations introduced by a thick optical element giving us the ability to generate correct computation models for rendering a virtual object in 3D space with the appropriate amount of distortion. The effects and the needs for such compensation are further demonstrated and validate through a user-centered depth perception experiment using an optical see-through HMD system.

9086-21, Session 8

Performance comparison between a head-worn display system and a head-up display for low visibility commercial operations

Jarvis J. Arthur III, Lawerence J. Prinzel III, NASA Langley Research Ctr. (United States); James R. Barnes, Unisys Corp. (United States); Steven P Williams, NASA Langley Research Ctr (United States); Denise R. Jones, NASA Langley Research Ctr. (United States); Stephanie J. Harrison, Old Dominion Univ. (United States); Randall E. Bailey, NASA Langley Research Ctr. (United States)

Research, development, test, and evaluation of flight deck interface technologies is being conducted by the National Aeronautics and Space Administration (NASA) to proactively overcome aircraft safety barriers that might otherwise constrain the full realization of NextGen. Under the Vehicle Systems Safety Technologies (VSST) project in the Aviation Safety Program, one specific area of research is the use of small Head-Worn Displays (HWDs) as an equivalent display to a Head-Up Display (HUD). Title 14 of the US Code of Federal Regulations (CFR) 91.175 describes a possible operational credit which can be obtained with airplane equipage of a Head-Up Display (HUD) or an "equivalent" display combined with Enhanced Vision (EV). If successful, a HWD may provide the safety and operational benefits that current HUD-equipped aircraft enjoy but for significantly more aircraft in which HUD installation is neither practical nor possible. A simulation experiment - described in this proposed paper - was conducted to evaluate if the HWD, coupled with a head-tracker, can provide an equivalent display to a HUD. Comparative testing was performed in the Research Flight Deck (RFD) Cockpit Motion Facility (CMF) at NASA Langley. Twelve airline crews conducted approach and landing, taxi, and departure operations during low visibility operations (1000', 300') at Memphis International Airport (FAA identifier: KMEM). The paper will describe the subjective and objective data collected from this research.

9086-22, Session 8

Helmet-mounted display utility for unguided precision airdrop application within non head-up-display equipped aircraft.

Eric E. Geiselman, Paul R. Havig II, John P. McIntire, Air Force Research Lab. (United States)

The Air Force Research Laboratory is executing a research program with the objective of developing technologies and procedures to increase the precision with which unguided cargo airdrop is accomplished. Simultaneously, program objectives include significantly decreasing the ownship threat exposure by affording higher-altitude single-pass drop profiles. Application of a helmet-mounted display (HMD)-based transparent display has the potential to aid this technology development in a number of significant ways. This paper discusses the potential technology advantages of HMD inclusion (visual release point appreciation, intensified vision, as well as wind profiling/ownship status derived continuously computed maneuvering guidance). Foreseeable technical challenges and potential application disadvantages are also discussed.

9086-23, Session 8

Augmented reality, and applications in education and training in military schools

Isa Haskologlu, Mehmet Sisman, Kara Harp Okulu (Turkey)

In this study we have worked with 3-D computer engineers in order to search the applicable fields of Augmented Reality in Military Training and Education in Military schools which needs give their students military tactics, history, as well as other lessons. we have find out that especially in the field of history, and military tactics Augmented Reality makes the subjects more understandable. We re now working on a project that can be used in history.

9086-24, Session 8

Evaluation of helmet-mounted display targeting symbology based on eye tracking technology

Lijing Wang, Xiaodong Liu, BeiHang Univ. (China)

Laboratory and flight test evaluations have consistently demonstrated the potential for helmet-mounted display (HMD) presented information to enhance air combat performance. One of our previous studies examining the ownship status HMD symbology (distributed flight reference and nondistributed flight reference, DFR and NDFR) on ergonomics showed that NDFR was more suitable for HMD than DFR. In this study, we compared two opposing color-coding strategies and three target symbologies in an air-to-air scenario with NDFR. The HMD was simulated by drawing the symbology on the scene displays, so eye tracking technology could be used in this research as a more objective and accurate method. The amount of time it took operators to make correct decisions on a simplified targeting task, error rates and Scanning trajectory were recorded as performance measure. The results of this study indicated that color-coded symbology and locator line with reflected vector length proved to be the preferred. A detailed description of experiment design and results of this study will be presented.

9086-25, Session 9

Helmet-mounted nighttime camera system

Tammy Orourke, Dan Marshall, DevCar, LLC (United States)

The invention includes an image-intensifier tube and circuitry coupled to a digital storage medium that periodically samples a signal provided by the image intensifier tube and stores the sampled image to be viewed in near real time or at a later date by a data analyst. The night vision system includes a casing surrounding the image intensifier tube and the associated circuitry along with a port for accepting a power and/or signal cable for providing power to the image intensifier tube and image signal to the signal storage medium. The system may further include a daytime camera and a switch for toggling the image signal data input to the digital storage medium between the daytime camera and the image intensifier tube.

Basic components include a wide-angle lens, image intensifier tube coupled to a CMOS sensor via relay lenses or fiber optics. This high definition image is saved on an internal solid-state memory chip. One-step button controls allow the user a positive on/off. Future development of compression software will allow for real-time streaming of video able to be relayed via personnel carried communication systems on the battlefield.

9086-26, Session 9

Virtual reality 3D headset based on DMD light modulators

Bruce E. Bernacki, Pacific Northwest National Lab. (United States); Allan Evans, Edward Tang, Avegant Corp. (United States)

We present the design of an immersion-type 3D headset suitable for virtual reality applications based upon digital micro-mirror devices (DMD). Current methods for presenting information for virtual reality are focused on either polarization-based modulators such as liquid crystal on silicon (LCoS) devices, or miniature LCD or LED displays often using lenses to place the image at infinity. LCoS modulators are an area of active research and development, and reduce the amount of viewing light by 50% due to the use of polarization. Viewable LCD or LED screens may suffer low resolution, cause eye fatigue, and exhibit a "screen door" or pixelation effect due to the low pixel fill factor. Our approach leverages a mature technology based on silicon micro mirrors delivering 720p resolution displays in a small form-factor with high fill factor. Supporting chip sets allow rapid integration of these devices into wearable displays with high-definition resolution and low power consumption, and many of the design methods developed for DMD projector applications can be adapted to display use. Potential applications include night driving with natural depth perception, piloting of UAVs, fusion of multiple sensors for pilots, training, vision diagnostics and consumer gaming. Our design concept is described in which light from the DMD is imaged to infinity and the user's own eye lens forms a real image on the user's retina realizing a virtual retinal display.

9086-27, Session 9

Head-up displays and head-down displays integration in automobiles

J. Alejandro Betancur, Gilberto Osorio, Alejandro Mejía, Univ. EAFIT (Colombia)

In automotive industry, the dashboard has been ergonomically developed in order to keep the driver focused on the horizon; the above is the principal point of development of this work, which seeks through the integration of Head-Up Displays and Head-Down Displays applied to automobiles, to propose configurations that give to drivers the facility to driving focused, without any necessity to manipulating the dashboard functions; consequently, it is presented some of the main ergonomic comments about those configurations; on the other hand, the amount of technical specifications in a system as here described is too much, but some technical comments regarding the implemented arrangements are given.

9086-28, Session 10

Smart filters: Operational HMD even at bright sunlight conditions

Ariela Donval, Noam Gross, Eran Partouche, Ido E. Dotan, Ofir Lipman, Moshe Oron, KiloLambda Technologies, Ltd. (Israel)

A typical Head Mounted Display (HMD) has either one or two small displays with relevant optics embedded in a helmet, eye-glasses (also known as data glasses) or visor. Some HMDs allow the computer generated image (CGI) to be superimposed on a real-world view. This method is often called Optical See-Through. In see-through HMD the background illumination is a crucial factor influence the ability of viewing the display. When using the HMD at a very bright day, the display image risks vanishing due to the sun illumination. However, at a very cloudy day, one needs all the light to pass through the display to the user eye. The need to control the amount of sunlight passes through the HMD was the trigger for our effort in developing Dynamic Sunlight Filter (DSF), which is a passive solution dedicated to regulate sunlight overpower events.

KiloLambda's Dynamic Sunlight Filter (DSF), is a passive solution dedicated for sunlight controlling and regulating applications. The DSF is a passive (self-adaptive), solid-state, free-space filter, which attenuates visible light variably according to its intensity. The DSF's transmittance is inversely proportional to the amount of solar light impinging on it. When light level is low, such as in the case of cloudy sky, the DSF remains transparent, with high transmission functionality.

As the light level is increased and gets more intense, such as in the case of direct sun, the DSF transmission decreases, eventually reaching a darkened state. This process is reversible and the filter returns to its transparent state once the intensity of light decreases to its normal level. When placing such a DSF at the outer face of the HMD, it provides the benefit of keeping background illumination at the desired level, regardless of the real weather conditions, such as bright sun or clouds. We present at this talk the DSF functionality including new capabilities as were developed within the last year to be adapted mostly for avionic applications. We discuss also the benefits for avionic and non-avionic HMD applications.

9086-29, Session 10

Scorpion hybrid optical-based inertial tracker (HObIT) test results

Robert Atac, Eric Foxlin, Tom Calloway, John Popoolapade, Thales Visionix, Inc. (United States)

Thales Visionix, Inc. presented a new helmet tracker based on a hybrid inertial optical approach in 2013. The Hybrid Optical based Inertial Tracker (HObIT) uses the inside-out concept and InterSense NavChip precision Inertial Measurement Unit (IMU). A unique feature of the tracker is that there is no aircraft mounted equipment. A few circular bar code like fiducial stickers are placed on the interior surface of the cockpit. The tracker allows operation in both hybrid inertial/optical and inertial alone. HObIT has been installed and successfully flown on a number of different platforms. This paper will describe the different installations and the performance achieved by the HObIT.

9086-30, Session 10

Gradient index eyepiece technology for head-mounted display applications

Peter L. Marasco, Air Force Research Lab. (United States)

Eyepieces used in full color head-mounted displays require a high degree achromatization to exhibit the level of performance required by observers. Many times, this leads to the use of dense glass materials and multi-element systems. The advent of new gradient index material systems as part of the DARPA-sponsored Manufacturable Gradient Index Optics (M-GRIN) may yield new design degrees of freedom for eyepiece and HMD designers. New plastic material systems that may be used to create achromatized singlets, simplifying eyepiece design and shortening the eyepiece overall length, pulling the entire HMD system closer to the observer's head and improving systems center of gravity. This paper will examine the possibility of using large aperture GRIN optics to achromatize an eyepiece and examine the impact on weight and volume. Assumptions about the material system (index of refraction (n) and delta n) and a candidate full color microdisplay will be clearly stated and may not reflect any commercially available system.

9086-32, Session 10

A versatile photogrammetric camera automatic calibration suite for multispectral fusion and optical helmet tracking

Jason P. de Villiers, Robert Jermy, Council for Scientific and Industrial Research (South Africa)

This paper presents a system to determine the photogrammetric parameters of a camera[1]. The lens distortion, focal length and camera six degree of freedom (DOF) position are calculated. The system caters for cameras of different sensitivity spectra and fields of view without any mechanical modifications.

The distortion characterisation [2], a variant of Brown's classic plumb line method [3], allows many radial and tangential distortion coefficients ands find the optimal principle point. Typical values are 5 radial and 3 tangential coefficients, these parameters are determined stably and demonstrably produce superior results [2] to low order models despite popular and prevalent misconceptions to the contrary [4]. The system produces coefficients to model both the distorted to undistorted direction (e.g. for target designation) and the undistorted to distorted direction (e.g. for image stitching and fusion) allowing deterministic rates far exceeding real time [5,6].

The focal length is determined to minimise the error in absolute photogrammetric positional measurement for both multi camera systems or monocular (e.g. helmet tracker) systems.

The system determines the 6 DOF position of the camera in a chosen coordinate system. It can also determine of the 6 DOF offset of the camera relative to its mechanical mount. This allows faulty cameras to be replaced with out requiring a recalibration of the entire system (such as an aircraft cockpit).

Results from two simple applications of the calibration results are presented: stitching and fusion of the images from a dual-band visual/LWIR camera array, and a simple laboratory optical helmet tracker.

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Conference 9087: Degraded Visual Environments (DVE): Enhanced, Synthetic, and External Vision Solutions (ESXVS) 2014

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9087-1, Session 1

3D surface imaging through visual obscurants using a sub-terahertz radar

Jason Fritz, Colorado Engineering, Inc. (United States); Albin J. Gasiewski, Univ. of Colorado at Boulder (United States); Lawrence Scally, Colorado Engineering, Inc. (United States); Kun Zhang, Univ. of Colorado at Boulder (United States)

High resolution, 3D imaging of terrestrial surfaces is most easily achieved using stereoscopic electro-optical (EO) sensors. However, passive EO sensors require light and cannot penetrate clouds, smoke, dust and other visual obscurants. 3D lidar has been used quite successfully to image in no/low light conditions and some obscurants. Millimeter wave (MMW) radar, even up to 94 GHz, can penetrate obscurants, but requires a much larger antenna and significant bandwidth to achieve a similar resolution. Current research activities are investigating whether or not sub-terahertz sensors, on the order of hundreds of gigahertz, can achieve high resolution 3D imagery yet be relatively small. This spectral region has seen minimal sensor development due to the combination of high water vapor absorption and low power sources. Recently, sources have become available that provide enough transmit power to overcome atmospheric absorption and scattering through these obscurants at distances of 100-200 m, and the available power will continue to increase while the device sizes will decrease. In order to achieve the full 3D surface reconstruction, a radar fan beam is scanned in one direction with two offset receivers collecting reflected energy. Using standard interferometry techniques, the phase difference between the two receivers is utilized to estimate the surface height at each pixel. Such as system has been built and initial outdoor imaging results will be presented. These results are preliminary and highlight the challenges at this frequency, but provide indications that this band may provide a solution to the problem.

9087-2, Session 1

Overview of the commercial OPAL lidar optimized for rotorcraft platforms operating in degraded visual environments

Philip M. Church, Neptec Technologies Corp. (Canada); Tim Paul, The Boeing Co. (United States); Kiatchai Borribanbunpotkat, Mike Sekerka, Neptec Technologies Corp. (Canada)

Neptec has developed a family of obscurant-penetrating 3D laser scanners called OPAL 2.0 that are being adapted for rotorcraft platforms. Neptec and Boeing have been working on an integrated system utilizing the OPAL LiDAR to support operations in degraded visual environments. OPAL scanners incorporate Neptec's patented obscurant-penetrating LiDAR technology which was extensively tested in controlled dust environments and helicopters for brownout mitigation. The OPAL uses a scanning mechanism based on the Risley prism pair. Data acquisition rates can go as high as 200kHz for ranges within 200m and 25kHz for ranges exceeding 200m. The scan patterns are created by the rotation of two prisms under independent motor control. The geometry and material properties of the prisms will define the circular field-of-view of the sensor, which can be set between 60 to 120 degrees. Through detailed simulation and analysis of mission profiles, the system can be tailored for application to rotorcraft. Examples of scan patterns and control schemes based on these simulations will be provided along with data density predictions versus acquisition time for applicable DVE scenarios. Preliminary 3D data acquired in clear and obscurant conditions will be presented and compared to theoretical predictions. A high-level overview of the OPAL sensor integration into such system will be also presented.

9087-3, Session 1

Low SWaP high-performance obscurant penetrating 3D lidar for helicopter situational awareness in DVE

James T. Murray, Jason Seely, Jeffrey J. Plath, William L. Ryder, Gregory J. Fetzer, Neil R. Van Lieu, Kelly Hillman, Tyler J. Wagner, Adam Knudson, Brian Lang, Kenneth Panici, John R. Engel, Andrea Smith, Matt Graham, John Bantle, Veeder South IV, Tracy Wadleigh, Tom Lombardo, Anthony M. Mitchell, Arete Associates (United States)

Imaging laser radar (ladar or lidar) is a promising DVE sensor technology because it can provide wide field-or-regard, high-resolution, 3-dimensional real-time imagery of the region surrounding a helicopter in severe DVE conditions. Areté Associates has developed and flight tested next-generation low SWaP, real-time dust-penetrating (DUSPEN) lidar system that is packaged for integration into a turreted sensor assembly.

Areté's DUSPEN system captures full lidar waveforms and uses sophisticated real-time detection and filtering algorithms to discriminate hard target returns from dust and other obscurants. Down-stream 3D image processing methods are used to enhance visualization of threat objects (e.g. wires, cables, poles, posts, foliage, obstacles, etc.) and ground features (e.g. ditches, berms, rocks, boulders, sloping terrain, etc.). Areté has developed sophisticated real-time sensor fusion algorithms to blend 2D and 3D imagery onto the cockpit display. These advanced fusion techniques are used to aid pilots in visualizing threat objects or terrain features derived from the see-through 3D lidar while viewing EO scene imagery derived from a high-definition visible, MWIR, or LWIR camera, or combination thereof.

9087-4, Session 2

DVE and the U.S. Army *(Invited Paper)*

Layne B. Merritt, U.S. Army Aviation & Missile Research, Development & Engineering Ctr. (United States)

No Abstract Available

9087-5, Session 3

Imaging through obscurants with a heterodyne detection-based ladar system

Randy R. Reibel, Peter A. Roos, Brant M. Kaylor, Trenton Berg, James Curry, Bridger Photonics, Inc. (United States)

Bridger Photonics has been researching and developing a ladar system based on heterodyne detection for imaging through brownout and other DVEs. There are several advantages that an FMCW ladar system provides compared to direct detect pulsed time-of-flight systems including: 1) Higher average powers, 2) Single photon sensitive while remaining tolerant to strong return signals, 3) Doppler sensitivity for clutter removal, and 4) More flexible system for sensing during various stages of flight. During this

talk, we will provide a review of our sensor, discuss lessons learned during various DVE tests, and show our latest 3D imagery.

9087-6, Session 3

Three-dimensional landing zone (3D-LZ) joint capability technology demonstration

James C. Savage, Air Force Research Lab. (United States)

The Three-Dimensional Landing Zone (3D-LZ) Joint Capability Technology Demonstration (JCTD) is a United States Central Command sponsored 27-month technology development program to develop and demonstrate an integrated Ladar and FLIR capability upgrade for the US Air Force Combat Search and Rescue (CSAR) HH-60G Pave Hawk helicopters through a retrofit of the current AN/AAQ-29 FLIR turret systems. The 3D-LZ JCTD builds upon a history of LADAR technology development programs for brownout. While preserving legacy FLIR capability, 3D-LZ will integrate a high-resolution, imaging LADAR to address helicopter approach and landing in degraded visual environments with emphasis on brownout; cable warning and obstacle avoidance; and controlled flight into terrain via Helicopter Terrain Awareness and Warning System (HTAWS). The LADAR subsystem will provide real-time geo-referencing, dust rejection and penetration, automatic cable and obstacle detection and warning, fusion of real-time LADAR data with a terrain database, and visual/audible aircrew warnings for terrain avoidance. This paper summarizes program progress to date, describes individual LADAR technologies within 3D-LZ, documents system performance metrics in each of the capability areas, and outlines the JCTD program plans which will culminate in a flight demonstration at Yuma Proving Ground in 2014.

9087-7, Session 3

Flight testing results of rotary-wing and fixed-wing millimeter-wave radar DVE solutions

John Schneider, Jack Cross, Pete Cariani, Sierra Nevada Corp. (United States)

This paper will summarize flight testing results of the Sierra Nevada Corporation (SNC) rotary-wing and fixed-wing millimeter wave radar enhanced vision products. For over a decade, SNC has developed and evolved these products that utilize a fast-scanning 94 GHz radar to produce three-dimensional measurement of the terrain within the radar field of view. The three-dimensional data is rendered as terrain and obstacle imagery on pilot and co-pilot displays with system and navigation state symbology overlays. The radar terrain imagery is fused with synthetic imagery of the surrounding terrain, derived from overhead EO imagery overlaid on DTED topographic information, to form a long-range, wide field-of-view display for pilot situational awareness. The rotary-wing system also includes brown-out guidance and symbology overlays to aid the pilot in landing at specific touch down locations input by the pilot or provided through a mission planning interface. The most recent version of the rotary-wing system has completed development and undergone extensive environmental and EMI/EMC testing in the past year for the US Army DVE ONS program. Multi-ship performance flight testing on the UH-60L platform will be completed in 2Q2014. This several month long flight test will be the most exhaustive test of a DVE system in operational flight conditions to date. Flight testing results of terrain/obstacle detection and landing guidance performance will be presented. The fixed-wing EFVS system, REVS, is being developed to address commercial aviation DVE mitigation, and has also successfully performed several developmental and demonstration flight tests. This paper summarizes the results of the DVE ONS and REVS flight testing events and other ongoing developmental efforts.

9087-8, Session 3

System modelling of a real-time passive millimetre-wave imager to be used for base security and helicopter navigation in degraded visual environments

Rupert N. Anderton, Colin D. Cameron, QinetiQ Ltd. (United Kingdom); Jeff J. Guell, The Boeing Co. (United States); Jack Sanders-Reed, Dennis J. Yelton, Boeing-SVS, Inc. (United States)

This paper discusses the design of an improved passive millimetre wave imaging system intended to be used for base security in degraded visual environments.

A simple end-to-end model of such an imager is described, including a simple scene model based on transformations applied to visible and infrared imagery, optical aberrations, focal plane sampling, scan conversion, receiver performance and image processing algorithms. The use of such a model as a design tool is discussed, especially with regard to optimising scan conversion and image processing algorithms. The expected performance improvements over previous imager designs reported are predicted.

9087-9, Session 4

Factors affecting advanced processing for visualisation of electro-optical distributed aperture sensor data in dynamic degraded visual environments

Stephen Bennett, Mark C. Lupton, SELEX ES Ltd. (United Kingdom)

There has long been a desire to operate rotorcraft as well in degraded visual environments, whether it is due to low light or to atmospheric obscurants, as on a clear day. This places certain expectations on the capabilities of the sensors and displays within any enhanced vision system to deliver a similar acuity, field of view, field of regard and dynamic response as the human vision system. Central to this is the ability of the processing elements of any such system to process high volumes of sensor data, with very low latency and to present display imagery via head mounted displays accurately registered to the outside world. Furthermore the ability to gracefully move from a good to a degraded visual environment and the augmentation of the vision system with supporting situation awareness information must be considered. This paper presents work undertaken to develop and assess, through aircraft flight trials, a real-time processing solution to provide enhanced situational awareness in degraded visual environments through an augmented vision system utilising distributed aperture sensors.

9087-11, Session 4

Development of reconfigurable image enhancement and multisensor fusion processor

Duncan L. Hickman, Moira I. Smith, Tektonex Ltd. (United Kingdom); Steve J. Parker, Fan Wu, RFEL Ltd. (United Kingdom)

The design and development of a high performance vision enhancement and processing system is reported which offers a highly flexible functional and physical architecture that can accommodated multiple camera inputs using a hybrid firmware and software processor. The architecture provides an application-tailored capability for both operator-viewed displays and assisted / automated applications with multiple high-data camera inputs (HD and up to 100Hz). Emphasis is placed on the development of a functional processing design that can provide significant operational gain in complex and challenging scenarios with degraded visibility.

Within this paper, the design approach is presented in terms of a trade-off discussion covering operational requirements, human-factors, algorithm

design, software, processor configuration, and the need for a flexible architecture. To deliver the required performance, a range of high-performance algorithms has been developed covering adaptive noise suppression, image manipulation (rotation, zoom, distortion correction), electronic stabilisation, contrast enhancement, registration, and fusion for two and three camera inputs. These capabilities are described and the performance illustrated using both laboratory and trials data. Key aspects of algorithm reconfiguration will also be discussed in term of both the algorithm and hardware designs including 'plug-and-play' interfacing. The achieved performance of the system will be demonstrated under different viewing conditions and the benefits to security and defence applications highlighted. Ongoing developments in the areas of motion sensing, segmentation, detection and tracking will also be discussed both in terms of implementation impact and user benefits. Finally, potential applications of the system are described with an emphasis on operational flexibility.

9087-12, Session 4

DVE: ground and airborne visualization functionalities

Dustin Franklin, GE Intelligent Platforms (United States); Andy Preece, GE Intelligent Platforms (United Kingdom); Larry Schaffer, GE Intelligent Platforms (United States); Nick Barrett, GE Intelligent Platforms (United Kingdom)

This paper describes functional blocks (hardware and software functionalities) applicable to several forms of indirect vision enhancement in DVE (Degraded Vision Environment for pilotage, Driver's Vision Enhancement for ground vehicle Situational Awareness). These functionalities are the result of the increased processing power of General Purpose Graphics Processing Units (GPGPUs) and improvements in mosaic stitch processing, image fusion and analytics of both live and synthetic imagery. We deploy GPUs into low-latency embedded systems with decreased SWaP and high-bandwidth interconnectivity via RDMA (Remote Direct Memory Access).

9087-13, Session 5

USAF/AFRL perspective on the challenges for DVE solutions *(Invited Paper)*

James C. Savage, U.S. Air Force (United States) and AFRL/RWWS (United States)

No Abstract Available

9087-14, Session 6

Degraded visual environment video quality metrics

Dustin D. Baumgartner, Bruce J. Schachter, Northrop Grumman Electronic Systems (United States); Eddie L. Jacobs, Jeremy B. Brown, Univ. of Memphis (United States)

A number of video quality metrics (VQMs) have been proposed for military operations in degraded visual environments. Some require both pristine and corrupted imagery. Others require patterned target boards in the scene. None of these metrics relates well to the task of landing a helicopter in conditions such as a brownout dust cloud.

We have developed objective VQMs to quantify the pilot's ability to detect hazards in the scene and to maintain situational awareness. The metrics are agnostic to sensor type. They have been validated with human perception experiments. Not only are the metrics suitable for evaluating algorithm and sensor variation, they are also suitable for choosing the most cost effective solution to improving operating conditions in degraded visual environments.

9087-15, Session 6

Image quality evaluations for enhanced vision system intended function and display

Carlo L. Tiana, Rockwell Collins, Inc. (United States); Weston J. Lahr, Rockwell Collins Aerospace & Electronics Inc. (United States); Brendan English, John A. Volpe National Transportation Systems Ctr. (United States)

The development trajectory for vision systems for low-visibility operations often places intense focus on the development of the sensing hardware. The hardware may have many applications to different platforms and for multiple purposes: vision through meteorological phenomena, vision through particulates such as sand and smoke, and vision through smog and haze from man-made emissions. The system will be deployed as a component of a complete platform that includes operational goals, display systems and various possible roles for the flying (or ground) crew.

Careful consideration must be given to the end to end integration of the vision system in the target platform and the selection of appropriate metrics to use when optimizing the system's performance. Tradeoffs and metrics are analyzed for some typical conditions.

9087-16, Session 6

External Vision Systems (XVS) Proof-of-Concept Flight Test Evaluation

Kevin J. Shelton, Steven P. Williams, Lynda J. Kramer, Jarvis J. Arthur III, Randall E. Bailey, NASA Langley Research Ctr. (United States)

NASA's Fundamental Aeronautics Program, High Speed project is performing research, development, test and evaluation of flight deck and related technologies to support future low-boom, supersonic configurations (without forward-facing windows) by use of an eXternal Visibility System (XVS). The challenge of XVS is to determine a combination of sensor and display technologies which can provide an equivalent level of safety and performance to that provided by forward-facing windows in today's aircraft. This flight test was conducted with the goal of obtaining performance data on see-and-avoid and see-to-follow traffic using a proof-of-concept XVS design in actual flight conditions. Six data collection flights were flown in ten traffic scenarios against two different sized participating traffic aircraft. This test utilized a 3x1 array of High Definition (HD) cameras, with a fixed forward field-of-view, mounted on NASA Langley's UC-12 test aircraft. Test scenarios, with particpating NASA aircraft serving as traffic, were presented to two evaluation pilots per flight – one using the proof-of-concept XVS and the other looking out the forward windows. The camera images are presented on the XVS display in the aft cabin with HUD like flight symbology overlaying the real-time imagery. The test generated XVS performance data, including comparisons to natural vision, and post-run subjective, workload, and acceptability data were also collected. The presentation will discuss the flight test activities, its operational challenges, and summarize the preliminary findings to date.

9087-17, Session 6

Visual advantage of enhanced flight vision system during NextGen flight test evaluation

Lynda J. Kramer, NASA Langley Research Ctr. (United States); Stephanie J. Harrison, Old Dominion Univ. (United States); Randall E. Bailey, NASA Langley Research Ctr. (United States); Kevin J. Shelton, NASA Langley Research Ctr (United States); Kyle K. Ellis, NASA Langley Research Ctr. (United States)

Synthetic Vision Systems and Enhanced Flight Vision System (SVS/EFVS)

technologies have the potential to provide additional margins of safety for aircrew performance and enable operational improvements for low visibility operations in the terminal area environment. Simulation and flight tests were jointly sponsored by NASA's Aviation Safety Program, Vehicle Systems Safety Technology project and the Federal Aviation Administration (FAA) to evaluate potential safety and operational benefits of SVS/EFVS technologies in low visibility Next Generation Air Transportation System (NextGen) operations. The flight tests were conducted by a team of Honeywell, Gulfstream Aerospace Corporation and NASA personnel with the goal of obtaining pilot-in-the-loop test data for flight validation, verification, and demonstration of selected SEVS operational and system-level performance capabilities.

Nine test flights were flown in Gulfstream's G450 flight test aircraft outfitted with the SEVS technology under low visibility instrument meteorological conditions. Evaluation pilots flew 108 approaches in low visibility weather conditions (600 ft to 3600 ft reported visibility) under different obscurants (mist, fog, drizzle fog, frozen fog) and sky cover (broken, overcast).

Flight test video were evaluated at three different altitudes (decision altitude, 100 ft radar altitude, and touchdown) to determine the visual advantage afforded to the pilot using the EFVS/FLIR imagery compared to natural vision. Results indicate the EFVS provided a visual advantage of two to four times over that of the out-the-window (OTW) view. The EFVS allowed pilots to view the runway environment, specifically runway lights, before they would be able to OTW with natural vision.

9087-18, Session 7

Honeywell synthetic vision avionics backbone (SVAB) program

Howard W. Wiebold, Honeywell Automation & Control Solutions (United States); Patrick L. O'Brien, Honeywell, Inc. (United States)

Rotorcraft experience nearly ten times the accident rate of fixed wing platforms, due in large part to the nature of their mission, requiring frequent operations in close proximity to terrain and obstacles. Degraded visual environments (DVE), including brownout or whiteout conditions generated by rotor downwash, result in loss of situational awareness during the most critical phases of flight, and are a significant contributor to the accident rate. Considerable research into sensor and system solutions to address DVE continues, however, the synthetic vision avionics backbone (SVAB) extends far beyond this single issue and enables improved situational awareness and mission effectiveness during all phases of flight and in all visibility conditions.

Advantages of a "sensor impartial" SVAB allow platform and mission diversity with an efficient upgrade path, even while research continues into new and improved sensors for use in DVE conditions. Through the optimum integration of multiple sources of information - sensor(s) data, terrain and obstacle databases, mission planning information, aircraft state information - enhancements to operations in all conditions and all phases of flight can be achieved.

Honeywell has recently completed flight testing for the DARPA Multi-Function RF program utilizing the SVAB with a real time MMW sensor. The system accurately detected obstacles, terrain and power lines, and displayed them in a realistic 3-D view on the current cockpit displays. Results will be shared.

9087-19, Session 7

Sensor-enhanced 3D conformal cueing for safe and reliable HC operation in DVE in all flight phases

Thomas R. Muensterer, Tobias Schafhitzel, Michael Strobel, Stephanus Klasen, AIRBUS Defence & Space (Germany)

Low level helicopter operations in degraded visual environment (DVE) still are a major challenge and bear the risk of potentially fatal accidents. DVE generally encompasses all degradations to the visual perception of the pilot ranging from night conditions via rain and snowfall to fog and maybe even blinding sunlight or unstructured outside scenery. Each of these conditions reduces the pilots' ability to perceive visual cues in the outside world reducing his performance and finally increasing risk of mission failure and accidents. The basis for the presented solution is a fusion of processed and classified high resolution ladar data with database information having a potential to also include other sensor data like forward looking or 360° radar data. This paper reports on a pilot assistance system aiming at giving back the essential visual cues to the pilot by means of displaying 3D conformal cues and symbols in a head-tracked helmet mounted display (HMD) and a combination with synthetic view on a head-down MFD. Each flight phase and each flight envelope requires different symbology sets and different possibilities for the pilots to select specific support functions. Several functionalities have been implemented and tested in a simulator as well as in flight. The symbology ranges from obstacle warning symbology via terrain enhancements through grids or ridge lines to different waypoint symbols supporting navigation. While some adaptations can be automated it emerged as essential that symbology characteristics and completeness can be selected by the pilot to match the relevant flight envelope and outside visual conditions.

9087-20, Session 7

Visual-conformal display format for helicopter guidance

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Helicopter guidance in situations where natural vision is reduced is still a challenging task. Beside new available sensors which are able to "see" through darkness, fog and dust, display technology remains one of the key issues of pilot assistance systems. As long as we have pilots within aircraft cockpits, we have to keep them informed about the outside situation. "Situational awareness" of humans is mainly powered by their visual channel. Therefore display systems which are able to fadeover seamless form natural vision to artificial computer vision and vice versa, are of greatest interest within this context. Helmet-mounted displays (HMD) have this property when they apply a headtracker for measuring the pilot's head orientation relative to the aircraft reference frame. Together with the aircraft's position and orientation relative to the world's reference frame the on?board graphics computer can generate images which are perfectly aligned with the outside world. We call image elements which match the outside world, "visual-conformal". Published display formats for helicopter guidance in degraded visual environment apply mostly 2D-symbologies which stay far behind from what is possible. We propose a perspective 3D-symbology for a head-tracked HMD which shows as much as possible visual-conformal elements. We implemented and tested our proposal within out fixed based cockpit simulator as well as in our flying helicopter simulator (FHS).

9087-21, Session 7

Synthetic vision meets ARINC 661: Feasibility study of different integration concepts for terrain visualization in ARINC 661 avionic displays

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The standard ARINC 661 Cockpit Display System Interfaces To User Systems is now being used increasingly for cockpit display systems development, e.g. in the Airbus A380, A350 or Boeing 787. The standard defines a client-server architecture including user applications (UA) which control layers in certain windows of a cockpit display system. When creating display systems for avionics, one can use a predefined set of simple and complex widgets. Simple widgets, for example, are lines, triangles, rectangles, circles while the more complex widgets are the translation or rotation container, the map widget or certain interaction widgets, amongst others. These are very useful when designing and programming a primary flight display (PFD) or navigation display (ND).

However, a proper widget or concept enabling a synthetic vision (SV) for terrain visualization has not yet been provided. Thus, the question is how to create SV PFD with ARINC 661 for a real-time safety-critical industrial environment. Accordingly, three different concepts, a standard, extended and independent concept are defined and described in this contribution. The standard concept tries to use the widgets provided by the ARINC 661 standard for terrain visualization. This approach is like a remote rendering of the terrain data outside the server. The extended concept includes a new customized widget as an extension of the widgets provided by the ARINC 661 standard. This widget adds terrain rendering features to the server. Hence, the customer widget has to be included in the server implementation. This extension is supported by the ARINC 661 standard but can only be supported by a server that includes this customer widget. The independent concept depicts an approach where the terrain visualization is independently computed outside the server and is merged by the graphics and video controller. The three concepts are qualitatively analyzed and weighed against each other.

On top of these results a hybrid concept is taken into consideration as prove-of-concept and for a detailed feasibility study. This hybrid concept combines a customized widget with an external non-safe rendering application, i.e. the terrain visualization will be controlled and integrated by a specific customer widget. The hybrid concept combining the advantages of the extended and the independent concept is implemented using the open source ARINC 661 tools called “j661” managed by Dassault Aviation. The implementation of the hybrid concept includes the development of a PFD using the j661 editor and the extension of the openGL functions of the j661 server. The implementation furthermore includes an X-Plane plugin enabling the use of X-Plane as rendering application for the terrain visualization. The prototyped concept is evaluated against the amount of date exchange and frames per second as well as latencies.

9087-22, Session 8

Long-range ISR systems in DVE *(Invited Paper)*

Ravi Athale, Office of Naval Research (United States)

No Abstract Available

9087-23, Session 9

Identifying opportune landing sites in degraded visual environments with terrain and cultural databases

Marc D. Moody, Robert Fisher, The Boeing Co. (United States)

A Degraded Visual Environment capability is presented that utilizes terrain and cultural databases to present the air crew with opportune landing sites and an approach vector with S-ILS cues to a designated landing zone. This technology may be extended to incorporate DVE sensors for improved near-earth situational awareness.

9087-24, Session 9

Detection of helicopter landing sites in unprepared terrain

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The primary usefulness of helicopters shows in missions where regular aircraft cannot be used. This might be due to requirements for landing in unprepared areas without dedicated runway structures, and an extended flexibility to fly to more than one previously unprepared target. One example of such missions are search and rescue operations. An important task of such a mission is to locate a proper landing spot near the mission target. Usually, the pilot would have to evaluate possible landing sites by himself, which can be time-intensive, fuel-costly, and generally impossible when operating in degraded visual environments.

We present a method for pre-selecting a list of possible landing sites. After specifying the intended size, orientation and geometry of the site, a choice of possibilities is presented to the pilot that can be ordered by means of wind direction, terrain constraints like maximal slope and roughness, and proximity to a mission target. The possible choices are calculated automatically either from a pre-existing terrain data base, or from sensor data collected during earlier missions, e.g., by collecting data with radar or laser sensors. Additional data like water-body maps and topological information can be taken into account to avoid landing in dangerous areas under adverse view conditions. In case of an emergency turnaround the list can be re-ordered to present alternative sites to the pilot.

We outline the principle algorithm for selecting possible landing sites, and we present examples of calculated lists.

9087-25, Session 10

DVE: Beyond the landing problem *(Invited Paper)*

H. Bruce Wallace, Defense Advanced Research Projects Agency (United States)

No Abstract Available

9088-1, Session 1

Graph-based hyperspectral image segmentation with improved affinity matrix

Lei Fan, David Messinger, Rochester Institute of Technology (United States)

Image segmentation and clustering is a method to extract a set of components whose members are similar in some way. Instead of focusing on the consistencies of local image characteristics such as borders and regions in a perceptual way, the spectral graph theoretic approach is based on the eigenvectors of an affinity matrix; therefore it captures perceptually important non-local properties of an image. A typical spectral graph segmentation algorithm, normalized cuts incorporates both the dissimilarity between groups and similarity within groups by capturing global consistency making the segmentation process more balanced and stable. For spectral graph partitioning, we create a graph-image representation wherein each pixel is taken as a graph node, and two pixels are connected by an edge based on certain similarity criteria. In most cases, nearby pixels are likely to be in the same region, therefore each pixel is connected to its spatial neighbors in the normalized cut algorithm. However, this ignores the difference between distinct groups or the similarity within a group. A hyperspectral image contains high spatial correlation among pixels, but each pixel is better described by its high dimensional spectral feature vector which provides more information when characterizing the similarities among every pair of pixels. Also, to facilitate the underlying scheme of removing edges between different groups, a penalization of the affinity matrix is also presented in this paper based on a derived edge-map, calculated using the HySPADE algorithm. Results will be shown for airborne hyperspectral imagery collected with the HyMAP sensor.

9088-2, Session 1

Wavelet packets and nonlinear manifold learning for analysis of hyperspectral data

John J. Benedetto, Wojciech Czaja, Timothy Doster, Catherine Schwartz, Univ. of Maryland, College Park (United States)

Hyperspectral geospatial data sets encode not only a wide range of the reflected electromagnetic spectrum in the form of radiance but also the intrinsic spatial information of the scene. To improve upon the results of any common application of hyperspectral data, i.e. classification, anomaly/target/change detection, both of these disparate sources of information, spatial and spectral, must be leveraged. There is a wide range of literature in the field of data fusion, specifically spatial-spectral fusion, for hyperspectral imaging. For example, previous work has examined exploiting spatial information via multilevel analysis, morphological profiles, operator fusion, deep learning, or minimal spanning forests. Wavelets offer another approach to the spatial-spectral fusion problem. Wavelets, by design, are adapt at capturing spatial correlations amongst data. For our methods we propose to use Wavelet Packets, which unlike Wavelets, decompose both the approximation and detail parts of the tree. By decomposing both parts of the tree, Wavelet Packets offer more than one basis per scale, and if the tree is decomposed fully to N levels, 2^2^(N-1) different signal representations are possible, thus offers additional flexibility over Wavelets. If an entropy function is defined across the bands, spectral correlations can be preserved during the best basis selection process. Thus Wavelet Packets are adapt at finding an optimal representation highlighting both the spatial and spectral components of the data. Wavelet Packets also offer the option of applying different scaling filters at each level of the Wavelet Packet Tree which can give further control to determining an optimal data representation.

In our algorithm, we propose to separately decompose each of the spectral bands by means of the Wavelet Packet Transform and then prune via a jointly defined energy function over all bands. Finally, to capture the non-linear nature of decomposed hypercube, output-normalized nonlinear manifold learning methods, such as Laplacian Eigenmaps, Diffusion Maps, or Local Linear Embedding, will be employed. This theory, though applicable to a wide range of datasets and applications, will be applied to the classification of hyperspectral images.

9088-3, Session 1

Schroedinger eigenmaps with nondiagonal potentials for spatial-spectral clustering of hyperspectral imagery

Nathan D. Cahill, Rochester Institute of Technology (United States); Wojciech Czaja, Univ. of Maryland, College Park (United States); David Messinger, Rochester Institute of Technology (United States)

Schroedinger Eigenmaps (SE) has recently emerged as a powerful graph-based technique for semi-supervised manifold learning and recovery. By extending the Laplacian of a graph constructed from hyperspectral imagery to incorporate barrier or cluster "potentials," SE enables machine learning techniques that employ expert/labeled information provided at a subset of pixels. In this paper, we show how different types of nondiagonal potentials can be used within the SE framework in a way that allows for the integration of spatial and spectral information in unsupervised manifold learning and recovery.

In the proposed framework, nondiagonal potentials encoding spatial proximity are added to the Laplacian of the original graph (which contains spectral proximity information). After solving a generalized eigenvector problem using the Schroedinger operator of the updated graph, the original image data can be represented in a lower dimensional space spanned by the dominant generalized eigenvectors. The lower-dimensional data can then be analyzed by state-of-the-art classification techniques.

To illustrate the practicality of the proposed SE framework, we performed experiments on publicly available hyperspectral images (Pavia University and Indian Pines). We used a subset of the ground-truth labels from these images to learn classifiers for predicting class labels from the reduced-dimensional data after its representation in the generalized eigenvector basis of the graph Schroedinger operator. When comparing our proposed approach with state-of-the-art spectral/spatial fusion approaches based on 1) combining eigenvectors from purely spatial and purely spectra Laplacian operators, 2) using fused Laplacian operators, and 3) using modified metrics in the graph construction, we found that SE is competitive/superior in nearly all cases.

9088-4, Session 1

Full-spectrum wavelet-based compression of hyperspectral imagery

Michael E. Winter, Pacific Spectral Technology (United States)

Hyperspectral sensors produce large quantities of data when operating on uninhabited aerial vehicles (UAV) that can overwhelm available data links. Technical Research Associates, Inc. designed, developed, and implemented a data compression approach that is capable of reducing this data volume by a factor of 100 or more with no loss in the tactical utility of the data. This algorithm, Full Spectrum Wavelet, combines efficient coding of the spectral dimension with a wavelet transformation of the spatial dimension. The approach has been tested on a wide variety of reflection band and thermal band hyperspectral data sets. In addition to such traditional measures as the error introduced by the compression, the performance of the algorithm was evaluated using application oriented measures such as Receiver

Operating Curves (ROC) and terrain categorization maps. Comparisons between these products showed little or no degradation of performance out to compression factors of 100. The evaluation procedure provided results directly relevant to tactical users of the data.

9088-5, Session 1

Effects of preprocessing applied to the compression of ultraspectral images

Rolando Herrero, Martin Cadirola, Ecotronics Ventures, LLC (United States); Vinay K. Ingle, Northeastern Univ. (United States)

One common approach to the compression of ultraspectral data cubes is by means of schemes where linear prediction plays an important role in facilitating the removal of redundant information. In general, compression algorithms can be seen as a sequence of stages where the output of one stage is the input of the following one. A stage that implements linear prediction relies heavily on a preprocessing stage that acts as a reversible procedure that rearranges the data cube and maximizes its spectral band correlation. In this paper we focus on AIRS (Atmospheric Infrared Sounder) images, a type of ultraspectral data cube, that involve more than two thousand bands and are excellent candidates to compression. Specifically we take into consideration several elements that are part of the preprocessing stage of an ultraspectral image. First, we explore the effect of Space Filling Curves (SFCs) as a way to provide a method to map an m-dimensional space into a highly correlated unidimensional space. In order to improve the overall mapping performance we propose a new scanning procedure that provides a more efficient alternative to the use of traditional state of the art curves. Second, we analyze, compare and introduce modifications to different band ordering and correlation estimation methods presented in the context of ultraspectral image preprocessing. Finally, we apply the techniques presented in this paper to a real AIRS compression architecture to obtain rate-distortion curves as a function of preprocessing parameters and determine the best scenario for a given linear prediction stage.

9088-6, Session 2

Retrieval of sand density from hyperspectral BRDF

Charles Bachmann, Andrei Abelev, U.S. Naval Research Lab. (United States); William Philpot, Cornell Univ. (United States); Katarina Z. Doctor, U.S. Naval Research Lab. (United States) and George Mason Univ. (United States); Marcos J. Montes, Robert A. Fusina, Rong-Rong Li, U.S. Naval Research Lab. (United States); Elena van Roggen, Marine Information Resources Corp. (United States)

In past work (Bachmann, Gray, Abelev, Philpot, et al, SPIE 2012), we have shown that density effects in hyperspectral BRDF data are consistent in laboratory goniometer data, field goniometer measurements with the NRL Goniometer for Portable Hyperspectral Earth Reflectance (GOPHER), and airborne CASI-1500 hyperspectral imagery. Density effects in granular materials have been described in radiative transfer models (Hapke, 2012), and are known, for example, to influence the size of the opposition effect. However, in coastal sands the relative change in reflectance with density depends on the composite nature of the sand (Bachmann, Philpot, Abelev, Korwan, submitted to Rem. Sens. Envir.). This paper examines the use of field hyperspectral goniometer data and its utility for retrieving sand density from airborne hyperspectral imagery. Field observations with GOPHER and coordinated airborne CASI data collected at the Virginia Coast Reserve LTER site and in Queensland, Australia form the basis of the study.

9088-7, Session 2

The relationship of variable moisture levels in coastal sands to hyperspectral BRDF data

Katarina Z. Doctor, George Mason Univ. (United States) and U.S. Naval Research Lab. (United States); Charles Bachmann, Marcos J. Montes, Andrei Abelev, U.S. Naval Research Lab. (United States); William Philpot, Cornell Univ. (United States); Rong-Rong Li, Robert A. Fusina, U.S. Naval Research Lab. (United States); Roy J. Hughes, Defence Science and Technology Organisation (Australia)

The reflectance of soil moisture levels in coastal sands varies with wavelength and includes several well-known liquid water absorption features. Reflectance also varies with angle of observation, however, current radiative transfer (RT) models for soils typically include moisture as a bulk extinction parameter (Lobell & Asner, 2002; Yang et al., 2011). In this study, we consider whether more detailed models can be developed and validated using our field observations of real coastal sands. We measured the bidirectional reflectance distribution function (BRDF) of sands with various moisture levels on beaches in Queensland, Australia and in Virginia's barrier island coasts using the NRL Goniometer for Outdoor Portable Hyperspectral Earth Reflectance (GOPHER). Analysis of variance of the BRDF over the hemispherical scan provides useful insight, especially since the wavelength dependence is often ignored in current radiative transfer models, while direct comparison with existing RT models provides a means of determining how these can best be modified to match the observations of real coastal sands. The BRDF shape in terms of the amount of forward-, backward-, and multiple scattering depends on more than one condition of the sand. In particular, the amount of surface water versus pore water plays an important role, as apparently does surface roughness.

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9088-8, Session 2

The influence of particle size on infrared reflectance spectra

Tanya L. Myers, Carolyn S. Brauer, Yin-Fong Su, Thomas A. Blake, Timothy J. Johnson, Pacific Northwest National Lab. (United States)

Reflectance spectra of solids are influenced by the absorption coefficient as well as the particle size and morphology. In the infrared, spectral features may be observed as either maxima or minima: in general, the upward-going peaks in the reflectance spectrum result from surface scattering, which are rays that have reflected from the surface without penetration, whereas downward-going peaks result from either absorption or volume scattering, i.e. rays that have penetrated or refracted into the sample interior and are not reflected. The light signal reflected from solids usually encompasses all these effects which includes dependencies on particle size, morphology and sample density. This paper measures the reflectance spectra in the 1.3 – 16 micron range for various bulk materials that have a combination of strong and weak absorption bands in order to understand the effects on the spectral features as a function of the mean grain size of the sample. The bulk materials were ground with a mortar and pestle and then sieved to separate the samples into various size fractions: 0-45, 45-90, 90-180, 180-250, 250-500, and >500 microns. The hemispherical spectra were recorded using a Fourier transform infrared spectrometer equipped with an integrating sphere to measure both the total and diffuse reflectance for all of the particle-size fractions. These studies clearly show that particle size has an enormous influence on the measured reflectance spectra for bulk

materials and that successful identification requires sufficient representative reflectance data to include the particle size of interest. Origins of the effects will be discussed.

9088-9, Session 2

Field collection of hyperspectral signatures

Brian Curtiss, PANalytical (United States)

Many forms of hyperspectral image exploitation rely on field collected hyperspectral signatures during the image analysis process. These signatures are typically collected from both targets of interest as well of background materials. Field collection of hyperspectral signatures is complicated by both the complexity of measurement systems as well as the requirement for stable atmospheric conditions. The complexity of current field portable spectrometer systems used to perform hyperspectral signature collections require a high level of operator training in order to assure the quality of collected signatures. For materials whose hyperspectral signature is not strongly dependent on illumination characteristics, it is possible to utilize a system with an internal light source. This simplifies collection for these materials since it eliminates the need for stable atmospheric conditions. To address other issues related to measurement system complexity, the workflow of the hyperspectral signature measurement process was first described in detail. By automating much of the repetitive portions of the workflow, the overall measurement process was, from the perspective of the instrument operator, greatly simplified. In addition to these improvements, system self-checks, such as automatic wavelength calibration verification, have been incorporated. These self-checks insure the proper operation of the system and provide a record of system performance during the collection period. These improvements combine to improve the productivity of field hyperspectral signature collection operations and to shorten the required training for instrument operators.

9088-10, Session 3

Hyperspectral target detection using graph theory models and manifold geometry via an adaptive implementation of locally linear embedding

Amanda K. Ziemann, David Messinger, James A. Albano, Rochester Institute of Technology (United States)

Hyperspectral images comprise, by design, high dimensional image data. However, research has shown that for a d-dimensional hyperspectral image, it is typical for the data to inherently occupy an m-dimensional space, with m<< d. In the remote sensing community, this has led to a recent increase in the use of non-linear manifold learning, which aims to characterize the embedded lower-dimensional, non-linear manifold upon which the hyperspectral data inherently lie. Classic hyperspectral data models include statistical, linear subspace, and linear mixture models, but these can place restrictive assumptions on the distribution of the data. With graph theory and manifold learning based models, the only assumption is that the data reside on an underlying manifold. In previous publications, we have shown that manifold coordinate approximation using locally linear embedding (LLE) is a viable pre-processing step for target detection with the Adaptive Cosine/Coherence Estimator (ACE) algorithm. Here, we improve upon that methodology using a more rigorous, data-driven implementation of LLE that incorporates spatially-adaptive windowing of the image. The LLE algorithm, which holds that the data is locally linear, typically is governed by a user defined parameter k, indicating the number of nearest neighbors to use in the initial graph model. We use an adaptive approach to building the graph that is governed by the data itself and does not rely upon user input. This implementation of LLE can yield greater separation between the target pixels and the background pixels in the manifold space. We present an analysis of target detection performance in the manifold coordinates using scene-derived target spectra, laboratory-measured target spectra, and ground truth target spectra.

9088-11, Session 3

Enough with the additive target model

Alan P. Schaum, U.S. Naval Research Lab. (United States)

The detection algorithms used most widely in reflective spectral imaging originated in hypothesis tests devised for communication and radar signal processing problems. For some applications, this legacy has led to operational algorithms that are a kluge of preprocessors based on faulty signal models, followed by ad hoc statistical tests to distinguish targets from confusers. We devise and solve an integrated detection model that posits several target and confuser exemplars. Sensed targets can appear in arbitrary mixtures with background pixels, and clutter can appear as arbitrary mixtures of confusers with background pixels. All materials are treated as opaque. Therefore, a replacement model must be used to describe the mixing, rather than the standard additive target model.

9088-12, Session 3

Vector tunnel algorithm for hyperspectral target detection

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The main objective of target detection is to search the pixels in a hyperspectral data cube for the existence of a specific material. For this purpose, the measured hyperspectral data is compared with the reflectance spectra of the material derived from field work or laboratory study [1-6].

Spectral signatures measured from samples of the same material are not fixed due to the inherent and external factors. Therefore, detection algorithms based on statistical analysis emerged by maximizing the probability of detection and minimizing the probability of false alarm. Although various detection algorithms using statistical information about targets and background classes have been developed over the years, insufficient training data and high dimensionality of spectra reduce the performance and effectiveness of these detectors [7-14].

Another solution might be a kernel method. Kernel methods map the input space nonlinearly into a higher dimensional space and thereafter utilize the underlying linear algorithm in the feature space. In this way, the complicated original data with nonlinear statistical characteristics are converted into a simpler data [15-17].

In this study, an efficient spectral similarity based hyperspectral target detection method which is called vector tunnel algorithm (VTA) is introduced. Targets and nontargets in a hyperspectral image are characterized in terms of their spectral features. Target detection problem is considered as a two-class classification process. The vector tunnel is characterized only by the target class information. To obtain the training data belonging to target class, the training regions are selected randomly. After determination of the parameters of the algorithms with the training set, decision procedures are accomplished at each pixel as target or background. Consequently, detection results are displayed as thematic maps. Then, the result of the method is compared with Euclidean Distance (ED), Spectral Angle Map (SAM), and Support Vector Machine (SVM) algorithms.

The proposed method may be summarized as in the following:

Step 1: If a priori target class information does not exist, the reference spectral signature from some hyperspectral data or spectral signature libraries is acquired for the initialization step.

Step 2: The target class vector tunnel parameters are defined according to shape of the spectral signature.

Step 3: By using tunnel parameters, n-dimensional target class vector tunnel

around the reference spectra is formed.

Step 4: Whole pixels in the image are tested whether they lie in the tunnel.

Step 5: If the spectral signature of the test pixel lies in the tunnel, it is labeled as target.

Step 6: If the test pixel is out of the tunnel boundaries, it is assigned to the background category.

Step 7: If a priori class information exists, training data are used to produce mean and standard deviation vectors for target class.

Step 8: By using the standard deviation vector as tunnel parameter, the vector tunnel is formed around the mean vector.

Step 9: Steps 4-6 are repeated to complete the detection process.

The proposed method is tested on AVIRIS Indiana's Pine and HYDICE Urban data. The algorithms are trained with the same training sets, and their comparative performances are tested under various cases. During these studies, various levels of thresholds are evaluated based on the efficiency of the algorithms by means of Receiver Operating Characteristic Curves (ROC) as well as visually. Quantitative detection results for AVIRIS data and visual classification results of HYDISE data will be given in the full paper.

9088-13, Session 3

Transductive and matched-pair machine learning for difficult target detection problems

James Theiler, Los Alamos National Lab. (United States)

Machine learning (ML) algorithms are potentially very powerful because they are flexible enough to model arbitrary distributions yet rigorous enough that one can prove theorems about their performance. The use of traditional ML for classification of remote sensing imagery is relatively straightforward and has already met with considerable success. The target detection problem is superficially similar to classification (it aims to distinguish target from non-target) but is in several important ways quite different. For target detection, only a few on-target training samples are typically available, the target strength can be variable, and the operation may need to be performed in a very low false alarm rate regime. Although many of the tools of ML -- kernels, regularization, cross-validation, etc. -- have proven useful for a number of remote sensing tasks, the traditional formulation of ML is not well suited to the target detection problem. This paper will describe the application of two non-traditional kinds of ML (transductive ML and the more recently proposed matched-pair ML) to the target detection problem. The approach combines explicit domain knowledge to model the target signal, with a more agnostic ML to characterize (without explicitly modeling) the background clutter. The concept is illustrated with experiments in the detection of gas-phase chemical plumes.

9088-14, Session 3

Gaussian/non-Gaussian subspace nonparametric target detector in inhomogeneous hyperspectral data

Gil A. Tidhar, Stanley R. Rotman, Ben-Gurion Univ. of the Negev (Israel)

Following the introduction of target detection algorithm by means of non-parametric density estimation in non-Gaussian subspace of measured hyperspectral data, we report in this work a new algorithm, based on information theory, to optimize Gaussian and non-Gaussian subspace division of the measured data. The algorithm allows for dimensionality reduction and topological simplification of the structure of the probability density of the non-Gaussian subspace. The non-Gaussian subspace is further divided into an independent-components non-Gaussian subspace and a dependent-components non-Gaussian subspace. These lower dimensionality subspaces are then treated differently in the target detection algorithm. ROC curves for the new algorithm show improvement with respect to former versions.

9088-15, Session 4

A comparison of real and simulated satellite/airborne multisensor imagery

Kevin Bloechl, Chris De Angelis, Michael G. Gartley, John Kerekes, Rochester Institute of Technology (United States); C. Eric Nance, Raytheon Intelligence & Information Systems (United States)

This paper examines the characteristics of simulated imagery in comparison to real imagery acquired with multiple sensors hosted on airborne and satellite platforms. The data set includes satellite and aerial multi- and hyperspectral imagery, as well as airborne LiDAR data, all with spatial resolutions of a few meters or less. The multispectral imagery includes data from commercial satellites as well as an airborne sensor with three-band visible color and calibrated radiance imagery in the long-, mid-, and short-wave infrared. The airborne hyperspectral imagery includes 360 bands of calibrated radiance and reflectance data spanning 400 to 2450 nm in wavelength. Collected in September 2012, the imagery is of a park in Avon, NY, and includes a dirt track and areas of grass, gravel, forest, and agricultural fields. A number of artificial targets were deployed in the scene prior to collection for purposes of target detection, subpixel detection, spectral unmixing, and 3D object recognition. For purposes of comparison, a synthetic reconstruction of the collection site was created in DIRSIG, an image generation and modeling tool developed by RIT, based on ground measured reflectance data, ground photography, and previous airborne imagery. Simulated satellite and airborne images were generated using the scene model, time of observation, atmospheric conditions, and knowledge of the sensor characteristics. The paper provides an in-depth comparison between the empirical and simulated images, including a discussion on the statistical differences between like areas within the images and a comparison of achieved performance for classification, detection and unmixing applications.

9088-16, Session 4

MODTRAN6: a major upgrade of the MODTRAN radiative transfer code

Patrick Conforti, Alexander Berk, Rosemary Kennett, Timothy Perkins, Frederick Hawes, Spectral Sciences, Inc. (United States); Jeannette van den Bosch, Air Force Research Lab. (United States)

The MODTRAN6 radiative transfer (RT) code is a major advancement over earlier versions of the MODTRAN atmospheric transmittance and radiance model. This version of the code includes improving the speed of the code, adding an interface to the code, providing modern software architecture, and upgrading the physics, including the incorporation of a line-by-line algorithm. Improvements to the execution of the code are made by introducing code parallelization to fully utilize multi-core and multi-processor hardware. The MODTRAN input is being redesigned to be more user friendly both in terms of text-based input as well as providing a GUI (Graphical User Interface). Additionally, an API (Application Programming Interface) is being developed for ease of integration into user applications. The MODTRAN code has been restructured towards a modular, object-oriented architecture to simplify upgrades as well as facilitate integration with other developers' codes. MODTRAN now includes a line-by-line algorithm for high resolution RT calculations as well as coupling to optical scattering codes (for easy implementation of custom aerosol and clouds) and customized atmosphere models.

9088-17, Session 4

A spectral climatology for atmospheric compensation

John H. Powell, Ronald G. Resmini, George Mason Univ. (United States)

Most hyperspectral imagery (HSI) detection and identification algorithms depend critically upon a robust atmospheric compensation capability to correct for the effects of the atmosphere on the Earth's surface radiance signal to derive the surface reflectance. Many methods have been developed to perform atmospheric compensation. They can broadly be categorized as either empirical methods, which derive the atmospheric coefficients from in-scene spectral information, or physics-based methods, which rely on explicit modeling of atmospheric propagation. Both approaches perform optimally when ancillary ground truth data is available, e.g., high fidelity in situ radiometric observations or atmospheric profile measurements.

When ground truth is incomplete or not available, additional assumptions must be made to perform the compensation. In the case of physics-based methods, meteorological climatologies are available to provide climatological norms for input into the radiative transfer models. No such climatologies exist for empirical methods, however. The success of atmospheric compensation methods such as the Empirical Line Method suggests that remotely sensed HSI scenes contain comprehensive sets of atmospheric state information within the spectral data. It is further argued that large collections of empirically-derived atmospheric coefficients collected over a range of climatic and atmospheric conditions comprise a resource that can be applied to future atmospheric compensation problems.

This paper introduces a new climatological approach to atmospheric compensation in which empirically derived spectral information, rather than sensible atmospheric state variables, is the fundamental datum. An experimental archive of airborne HSI data is mined for representative atmospheric compensation coefficients, which are assembled in a scientific database of spectral and sensible atmospheric observations. We present the empirical techniques for extracting the coefficients, the modeling methods used to normalize the coefficients across varying collection and illumination geometries, and the resulting derived climatological classes. Preliminary results from applying the database to atmospheric compensation problems are presented, along with a discussion of the potential benefits, shortfalls and limits of applicability of the new technique.

9088-18, Session 4

A smile effect correction method for dispersive imaging spectrometer based on relative radiometric calibration

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The hyperspectral images obtained from dispersive imaging spectrometer often contain significant cross-track spectral curvature, known as the smile/frown effect, which is due to the change of dispersion angle with field position. The smile effect must be corrected because the across-track wavelength shift from central wavelength alters the pixel spectra and reduces the application values on classification and target recognition. There are several methods to correct the smile effect which don't take into account the fact that the smile effect is woven together with the sensor radiation characteristics, and just processing spectra distortion to correct the smile effect. These methods would renewably lead to radiometric distortion of the radiometric correction image. This paper presents a new method to deal with this problem.

Firstly, the CCD relative radiometric correction model is analyzed in consideration of the inconsistent radiative response characteristics of CCD array and the dispersion angle changing with viewing field position. Secondly, the relative radiometric and spectral laboratory calibration of the dispersive imaging spectrometer is carried out and the relative radiometric calibration data together with the actual central wavelength of each detector are obtained. Then, the interpolated approximation of relative radiometric calibration data at actual central wavelength is taken into the CCD relative radiometric correction model, and radiometric calibration coefficients considered spectra distortion effect are obtained. Finally, hyperspectral images are corrected by the relative radiometric correction model and interpolation at the corrected central wavelength.

An actual image test for the proposed method is conducted. Hyperspectral images are acquired from a UAV-borne Offner Spectral Imager which has a spectral coverage of 0.395~1.028μm. The band of the corrected image at 760nm, i.e. the absorption peak of O2, has become consistent in tone which indicates that the smile effect is effectively removed, and meanwhile the relative radiometric correction result is finely reserved.

9088-19, Session 5

Multispectral, hyperspectral, and lidar remote sensing and geographic information fusion for improved earthquake response

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The Naval Postgraduate School (NPS) Remote Sensing Center (RSC) and research partners have completed a remote sensing pilot project in support of California post-earthquake-event emergency response. The project goals were to dovetail emergency management requirements with remote sensing capabilities to develop prototype map products for improved earthquake response. NPS coordinated with emergency management services and first responders to compile information about essential elements of information (EEI) requirements. A wide variety of remote sensing datasets including multispectral imagery (MSI), hyperspectral imagery (HSI), and LiDAR were assembled by NPS for the purpose of building imagery baseline data; and to demonstrate the use of remote sensing to derive ground surface information for use in planning, conducting, and monitoring post-earthquake emergency response. Worldview-2 data were converted to reflectance, orthorectified, and mosaicked for most of Monterey County; CA. Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data acquired at two spatial resolutions were atmospherically corrected and analyzed in conjunction with the MSI data. LiDAR data at point densities from 1.4 pts/ m2 to over 40 points/ m2 were analyzed to determine digital surface models. The multimodal data were then used to develop change detection approaches and products and other supporting information. Analysis results from these data along with other geographic information were used to identify and generate multi-tiered products tied to the level of post-event communications infrastructure (internet access + cell, cell only, no internet/cell). Technology transfer of these capabilities to local and state emergency response organizations gives emergency responders new tools in support of post-disaster operational scenarios.

9088-20, Session 5

Estimating radiological background using imaging spectroscopy

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Optical imaging spectroscopy is investigated as a method to estimate radiological background by spectral identification of soils, sediments, rocks, minerals and building materials derived from natural materials and assigning tabulated radiological emission values to these materials. Radiological airborne surveys are undertaken by local, state and federal agencies to identify the presence of radiological materials out of regulatory compliance. Detection performance in such surveys is determined by (among other factors) the uncertainty in the radiation background; increased knowledge of the expected radiation background will improve the ability to detect low-activity radiological materials. Radiological background due to naturally occurring radiological materials (NORM) can be estimated by reference to previous survey results, use of global 40K, 238U, and 232Th (KUT) values, reference to existing USGS radiation background maps, or by a moving average of the data as it is acquired. Each of these methods has its drawbacks: previous survey results may not include recent changes in the survey area, the global average provides only a zero-order estimate, the USGS maps are coarse and are accurate only to 1 km – 5 km sampling intervals, and a moving average may essentially low pass filter the data to obscure small changes in radiation counts. Imaging spectroscopy from airborne or spaceborne platforms can offer higher resolution identification of materials and estimated background, as well as provide imaging context information. AVIRIS hyperspectral image data is analyzed using commercial exploitation software to determine the usefulness of imaging spectroscopy to identify qualitative radiological background emissions when compared to airborne radiological survey data.

9088-22, Session 5

Subsurface unmixing for benthic habitat mapping using hyperspectral imagery and lidar-derived bathymetry

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Mapping of benthic habitats from hyperspectral imagery can be achieved by integrating bio-optical models with common techniques for hyperspectral image processing, such as spectral unmixing. Several algorithms have been described in the literature to compensate or remove the effects of the water column and extract information about the benthic habitat characteristics utilizing only measured hyperspectral imagery as input. More recently, the increasing availability of lidar-derived bathymetry information offers the possibility to incorporate this data into existing algorithms, thereby reducing the number of unknowns in the problem, for the improved retrieval of benthic habitat properties. This study demonstrates how bathymetry information improves the mapping of benthic habitats using two algorithms that combine bio-optical models with linear spectral unmixing. Hyperspectral data, both simulated and measured, in-situ spectral data, and lidar-derived bathymetry data are used for the analysis. The simulated data is used to study the capabilities of the selected algorithm to improve estimates of benthic habitat composition by combining bathymetry data with the hyperspectral imagery. Hyperspectral images captured over Enrique and Media Luna Reefs in Puerto Rico using an AISA Eagle sensor are used to further test the algorithms using real data. Results from analyzing this imagery demonstrate increased agreement between algorithm output and existing habitat maps and ground truth when bathymetry data is used jointly with hyperspectral imagery.

9088-23, Session 5

Parallax mitigation for hyperspectral change detection

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A pixel-level Generalized Likelihood Ratio Test (GLRT) statistic for hyperspectral change detection is developed to mitigate false change caused by image parallax. Change detection, in general, represents the difficult problem of discriminating significant changes opposed to insignificant changes caused by radiometric calibration, image registration issues, and varying view geometries. We assume that the images have been registered, and each pixel pair provides a measurement from the same spatial region in the scene. Although advanced image registration methods exist that can reduce misregistration to subpixel levels; residual spatial misregistration can still be incorrectly detected as significant changes. Similarly, changes in sensor viewing geometry can lead to parallax error in an urban cluttered scene where height structures such as buildings appear to move. Our algorithm looks to the inherent relationship between the image views and the theory of stereo vision to perform parallax mitigation leading to a search result in the assumed parallax direction. Validation of mitigating the parallax-induced false alarms is demonstrated using hyperspectral data in the experimental analysis. The algorithm is examined and compared to the existing chronochrome anomalous change detection algorithm to assess performance.

9088-24, Session 6

First observations on the SPICE hyperspectral dataset

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The Spectral and Polarimetric Imagery Collection Experiment (SPICE) is an ongoing collaborative effort between the Army Research Laboratory and US Army ARDEC, focusing on the longwave and midwave infrared (LWIR and MWIR) hyperspectral and polarimetric sensing modalities. The overall objective of SPICE is to collect a comprehensive database of both modalities spanning multiple years to capture sensor performance in a wide variety of meteorological conditions, diurnal, and seasonal changes inherent to a northern New Jersey location. From a tower at a hilltop (combined height: 0.15 km; slant range to target site: 5.7 km), the sensors have been autonomously collecting the desired data around the clock of three surrogate 2S3 Self-Propelled Howitzer targets posed at different orientations in an open woodland field. A highly reflective aluminum plate is also included in the scene to play the role of upwelling toward the sensors the downwelling sky and environment radiance. Since 2010, the effort has collected an unprecedented dataset of over 25,000 LWIR hyperspectral data cubes, 15,000 LWIR polarimetric data cubes, and 3,000 MWIR hyperspectral data cubes. This paper discusses results of our first observations on the LWIR hyperspectral dataset for pattern recognition applications, as multiple multivariate mathematical statistics and machine learning concepts are employed. Emphases are placed on data quality; validation of expected atmospheric spectral features; validation against another dataset of the same site, but collected by a different LWIR hyperspectral sensor; and challenges associated with using LWIR hyperspectral data for target detection and identification applications.

9088-25, Session 6

Bobcat 2013: a hyperspectral data collection supporting the development of spatial-spectral algorithms

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The amount of hyperspectral imagery (HSI) data currently available is relatively small compared to other imaging modalities, and what is suitable

for developing, testing, and evaluating spatial-spectral algorithms is virtually non-existent. In this work, a significant amount of coincident airborne hyperspectral and high spatial resolution panchromatic imagery that supports the advancement of spatial-spectral feature extraction algorithms was collected to address this need in April 2013 by the Civil Air Patrol for Ohio University with the Airborne Real-time Cueing Hyperspectral Enhanced Reconnaissance (ARCHER) sensor. The target materials, shapes, and movements throughout the collection area were chosen such that evaluation of change detection algorithms, atmospheric compensation techniques, image fusion methods, and material detection and identification algorithms is possible. This paper describes the collection plan, data acquisition, and initial analysis of the collected imagery.

9088-26, Session 6

First results from the hyperspectral imager for climate science (HySICS)

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The 2007 National Research Council Decadal Survey for Earth Science identified needed measurements to improve understanding of the Earth's climate system, recommending acquiring Earth spectral radiances with an unprecedented 0.2% absolute radiometric accuracy to track long-term climate change and to improve climate models and predictions. Current space-based imagers have radiometric uncertainties of ~2% or higher limited by the high degradation uncertainties of onboard solar diffusers or calibration lamps or by ground scenes viewed through the Earth's atmosphere.

The HyperSpectral Imager for Climate Science (HySICS) is a spatial/spectral imaging spectrometer with an emphasis on radiometric accuracy for such long-term climate studies based on Earth-reflected visible and near-infrared radiances. The HySICS's accuracy is provided by direct views of the Sun, which is more stable and better characterized than traditional flight calibration sources. Two high-altitude balloon flights provided by NASA's Wallops Flight Facility and NASA's Columbia Scientific Balloon Facility will demonstrate the instrument's intended 10? improvement in radiometric accuracy over existing instruments. We present the results of the first of these flights, during which measurements of the Sun, Earth, and lunar crescent were acquired from 37 km altitude.

Covering the entire 350-2300 nm spectral region needed for shortwave Earth remote sensing with the HySICS's single, flight-heritage detector array promises mass, cost, and size advantages for eventual space- and air-borne missions. A 6-nm spectral resolution with a 0.5-km spatial resolution from low Earth orbit helps in the determination of atmospheric composition, land usage, vegetation, and ocean color.

9088-27, Session 6

Analysis of spaceborne hyperspectral applicative land and ocean mission (SHALOM) with 10m ground resolutuion

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The system technical parameters shall be described. Then - systematic analysis of daily annual area coverage and throughput is provided. Finally - the quality of some typical L3 data products is demonstrated using simulation.

9088-28, Session 6

ATHOS: airborne thermal hyperspectral observation system: An introduction and overview of a gimbaled airborne LWIR hyperspectral imaging system

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ATHOS (Airborne Thermal Hyperspectral Observation System) is a long wave infrared (LWIR) hyperspectral imaging (HSI) system based on Lawrence Livermore's DS-3 spectrometer. Exelis has integrated the system and its optics into 20" gimbal to facilitate multiple collection modes. It is flown on a Cessna Caravan and collects LWIR hyperspectral data in both nadir and off-nadir configurations. In addition, improvements to its cryo-cooler have been implemented to facilitate temperature stability and improve its long-term reliability. This paper provides an overview of the sensor, its collection modes, and improvements to its cryo-cooler. Results of flight testing from the fall of 2013 are also reviewed. The results include an overview of sensor calibration and performance and examples of gas and solid material detection and identification. Future plans for additional flight test and the integration of VNIR and SWIR hyperspectral sensors into the gimbal will also be discussed.

9088-49, Session Posters-Tuesday

Local imaging from global measurements applied to selective-spectral imaging

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In this paper we describe the algorithm for local image reconstructions from global measurements on the Focal Plane Array. The global measurements may come from a multiplexed imaging and/or convolution-based sampling model. The algorithm consists of scanning a rectangular segment on the FPA data and reconstructing the image on that segment using a Least Square Estimator by adapting the measurements on the data via a linear operator. This method is essential in the reconstruction of large format images from large data samples. In particular, in this paper the method is applied to multiplexed, multispectral imaging from a single measurement on the FPA.

9088-50, Session Posters-Tuesday

Proper spectral band adjustment for coloristic feature-based recognition of safety signs

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The development of multi and hyperspectral systems in the area of civil security have created new opportunities with regard to mobile sampling as well as rapid detection for on-site analysis. The latest developments especially, in the area of optical detectors and the constant improvements to microprocessor computing capacity, have had and continue to have an enormous influence on coloristic analysis methods. Ongoing optimization of multispectral systems is leading to a vast quantity of new application scenarios due to the measuring systems that have been simplified and the achieved independence of specialized lab environments. The objective is to adapt the algorithm developed during the applicant's dissertation to a selection of suitable spectral bands, from monochrome powder specimens to panchromatic safety signs.

In this paper we present a coloristic feature-based procedure to provide the opportunity to start where geometric pattern recognition does not produce any clear results. The thrust of this research endeavor involves developing further the implemented analytical procedure for a suitable selection of spectral bands. To examine which bands provide a high information density, a virtual test environment is used. The photocurrent j = ∫ E(?)*Sabs(?)*R(?) d? was calculated for different light sources E, spectral response curves Sabs (bands), and the reflectance R of safety signs. Whether we can gain any knowledge from this the multivariate data set will have to be determined. The employed factor analysis is a common method in the group of structure-discovering methods, and provides good results in the discovery of connections between parameters. It is used particularly if a variety of parameters must be reduced for a certain question. For the verification, a dimension of the external separation must be defined. For this a n-dimensional vector P must be assigned to each measurement, that is registered in the matrix M. To determine the volume V of this dot cloud, the dimension normalized volume is defined as ?CL = sqrt (4^n-3/5^4 * sqrt (V = det MT * det M)), where n is the quantity of employed bands.

The measuring system is intended to place only marginal demands on the environmental conditions to be practically independent of highly specialized lab environments. The results are available within a few seconds, and combination evidence are possible, i.e. usability in time-critical applications should be able to be achieved where a high output is required. In this way, demands made on the personnel (the human factor) are markedly reduced, which becomes even more important when considering that optimum environmental conditions cannot always be assumed when making an assessment.

As a result we adapt spectral systems or where this was impossible we optimized the data processing to increase the rate of recognition. The aim is to achieve multivariate identification of the efficiency of complex measuring systems in the context of complex safety chains.

The use of such optimized multispectral photodiodes would simplify and accelerate the identification of safety signs for automotive, civil security and defense applications.

9088-51, Session Posters-Tuesday

Retrieval of atmospheric CO_2 using ground-based hyperspectral observation

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Atmospheric carbon dioxide (CO2) concentration measures ground-based hyper-spectral observations is one of the most important data sources to validate and improve satellite hyper-spectral observations of CO2. In this study, the ground-based CO2 concentrations observation experiment was conducted in the sites of Grassland and Crop land in China. Based on spectral absorption features of atmospheric CO2, we retrieved the column-averaged CO2 dry-air mixing ratio (XCO2) using the hyperspectral data obtained from this observation experiment. We made a detailed quantitative analysis for evaluating the influence on XCO2 retrieval accuracy with wavelength shift in spectral observation and the meteorological parameters, which are main factors affecting retrieval accuracy,. The results show the deviation of XCO2 retrievals was more than 1 ppm, and the fitting residuals exceed the setting threshold value of the fitting algorithm if the wavelength shifts were larger than 0.042 nm. The spectral transmittance within the three spectral ranges, 6357-6358cm-1, 6360-6361cm-1 and 6363-6364cm-1, is sensitive to the change of meteorological parameter change. These results are expected to provide references for the development and improvement of XCO2 retrieval algorithm based on ground-based hyperspectral.

9088-52, Session Posters-Tuesday

A color calibration method for spectral image based on radiative transfer mechanism

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Acquisition of true-color image that conformed to the human vision from multi/hyper-spectral images, will have great benefits to interpretation and analysis of the remote sensing data. Up to now, the three channels located in the red, green and blue bands are arbitrarily selected, which would cause significant difference with comparison to our a priori knowledge. However, the degradation of the sensors will also reduce the effects of color composition. Therefore, it becomes difficult to obtain the true color image robustly and efficiently with multi/hyper-spectral images.

In this paper, a physical based color calibration method is proposed base on spectral luminosity colorimetric theory. First, a true color image is constructed by the weighted integration of the spectral images and the color matching functions. Then, combining the in situ measurements of the spectrum of artificial targets, the theoretical truth colors of the targets are deduced with the radiative transfer model. At last, the color calibration model is established between the constructed colors and the theoretical colors. And this calibration model will perform over the whole image.

The proposed method was applied to the aerial hyperspectral image. In the flight campaign, in situ measurement of reflectance spectrum of different colored targets was simultaneously carried out, as well as the atmospheric parameters. After the color calibration, the corrected image appears much better than the uncorrected one. Therefore, the proposed method can efficiently improve the effects, though there are still a bit difference between the calibrated color and the theoretical color.

9088-53, Session Posters-Tuesday

Band selection in hyperspectral imagery using sparse support vector machines

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In this paper we propose an l1-norm penalized sparse support vector machine (SSVM) as an embedded approach to the hyperspectral imagery band selection problem. SSVMs exhibit a model structure that includes a clearly identifiable gap between zero and non-zero weights that permits important bands to be definitively selected in conjunction with the classifation problem. The SSVM Algorithm is trained using bootstrap aggregating to obtain a sample of SSVM models to reduce variability in the band selection process. This preliminary sample approach for band selection is followed by a secondary band selection which involves retraining the SSVM to further reduce the set of bands retained. We propose and compare three adaptations of the SSVM band selection algorithm for the multiclass problem. Two extensions of the SSVM Algorithm are based on pairwise band selection between classes. Their performance is validated by using one-against-one (OAO) SSVMs. The third proposed method is a combination of the filter band selection method WaLuMI in sequence with the (OAO) SSVM embedded band selection algorithm. We illustrate the perfomance of these methods on the AVIRIS Indian Pines and compare the results to other techniques in the literature. Additionally we illustrate the SSVM Algorithm on the Long-Wavelength Infrared (LWIR) data set consisting of hyperspectral videos of chemical plumes.

9088-29, Session 7

Multisensor data fusion across time and space

Pierre V. Villeneuve, Scott G. Beaven, Space Computer Corp. (United States); Robert A. Reed, Arnold Engineering Development Ctr. (United States)

Field measurement campaigns typically deploy numerous sensors having different sampling characteristics for spatial, temporal, and spectral domains. Data analysis and exploitation is made more difficult and time consuming as the sample data grids between sensors do not align. This report summarizes our recent effort to demonstrate feasibility of a processing chain capable of "fusing" image data from multiple independent and asynchronous sensors into a form amenable to analysis and exploitation using commercially-available tools.

Two important technical issues were addressed in this work: 1) Image spatial registration onto a common pixel grid, 2) Image temporal interpolation onto a common time base. The first step leverages existing image matching and registration algorithms. The second step relies upon a new and innovative use of optical flow algorithms to perform accurate temporal up-sampling of slower frame rate imagery. Optical flow field vectors were first derived from high-frame rate, high-resolution imagery, and then finally used as a basis for temporal up-sampling of the slower frame rate sensor's imagery. Optical flow field values are computed using a multi-scale image pyramid, thus allowing for more extreme object motion. This involves pre-processing imagery to varying resolution scales and initializing new vector flow estimates using that from the previous coarser-resolution image.

Overall performance of this processing chain is demonstrated using sample data involving complex motion observed by multiple sensors mounted to the same base. Multiple sensors were included, including a high-speed visible camera, up to a coarser resolution LWIR camera.

9088-30, Session 7

Simultaneous spectral analysis of multiple video sequence data for LWIR gas plumes

Justin Sunu, Jen-Mei Chang, California State Univ., Long Beach (United States); Andrea L. Bertozzi, Univ. of California, Los Angeles (United States)

We consider the challenge of detection of chemical plumes in hyperspectral image data. Segmentation of gas is difficult due to the diffusive nature of the cloud. The use of hyperspectral imagery provides non-visual data for this problem, allowing for the utilization of a richer array of sensing information. We consider several videos of different gases taken with the same background scene. One can simultaneously analyze frames from multiple videos using efficient algorithms for high dimensional data such as spectral clustering combined with linear algebra methods that leverage either subsampling or sparsity in the data. We also explore manifold denoising methods for such datasets, a method that solves an inverse diffusion process. With manifold denoising, we are able to bring more pertinent eigenvectors to the forefront. Analysis of multiple frames by the Nyström extension shows the ability to differentiate between different gasses while being able to group the similar items together, such as gasses or background signatures. Nyström extension allows for fast computations of the approximate eigenvalues and eigenvectors of the graph Laplacian. Spectral clustering can also be used to compute the true eigenvectors and eigenvalues of the graph Laplacian, for more accurate results.

9088-31, Session 7

Long-wave infrared surface reflectance spectra retrieved from Telops Hyper-Cam imagery

Steven M. Adler-Golden, Patrick Conforti, Spectral Sciences, Inc. (United States); Marc-André Gagnon, Pierre Tremblay, Martin Chamberland, Telops (Canada)

Processing long-wave infrared (LWIR) hyperspectral imagery to surface emissivity or reflectance units via atmospheric compensation and temperature-emissivity separation (TES) affords the opportunity to remotely classify and identify solid materials with minimal interference from atmospheric effects. This paper describes an automated atmospheric compensation and TES method, called FLAASH-IR (Fast Line-of-sight Atmospheric Analysis of Spectral Hypecubes – Infrared), and its application to ground-to-ground imagery taken with the Telops Inc. Hyper-Cam interferometric hyperspectral imager. The results demonstrate that clean, quantitative surface spectra can be obtained, even with highly reflective (low emissivity) objects such as bare metal and in the presence of some illumination from the surroundings. In particular, the atmospheric compensation process suppresses the spectral features due to atmospheric water vapor and ozone, which are especially prominent in reflected sky radiance.

9088-32, Session 7

Hyperspectral chemical plume quantification and temperature estimation

Sidi Niu, Northeastern Univ. (United States); Steven E. Golowich, MIT Lincoln Lab. (United States); Vinay K. Ingle, Northeastern Univ. (United States); Dimitris G. Manolakis, MIT Lincoln Lab. (United States)

Most hyperspectral chemical gaseous plume quantification algorithms assume a priori knowledge of the plume temperature either through direct measurement or an auxiliary temperature estimation approach. Plume quantification performance is highly sensitive to the accuracy of the plume temperature estimates, especially when the thermal contrast between the plume and background is low. Therefore, accurate plume temperate estimates are critical. However, existing approaches to plume temperature estimation incur a loss in spatial resolution, which leads to performance loss for these algorithms.

In this paper, we propose a new quantification algorithm that can simultaneously estimate the plume strength as well as its temperature. We impose only a mild spatial assumption, that at least one nearby pixel shares the same plume parameters as the target pixel. We believe this assumption will be easily satisfied in practice, with candidate pixels lying in a direction perpendicular to that of the ambient air flow. Simulations show that the performance of this new algorithm is comparable to that when the plume temperature is known exactly.

9088-33, Session 7

Hyperspectral image fusion using band reduction and contourlets

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Hyperspectral (HS) images have relatively low spatial resolution, compared to high-resolution single band panchromatic (PAN) images. Therefore, fusing an HS image with a PAN image has been widely studied to produce a high-resolution HS image. However, raw HS images are too large to process and contain redundant information that is not utilized in the fusion process. In this study, we propose a novel fusion method that employs an HS band reduction and contourlets.

The HS band reduction method divides a total number of spectral bands into multiple subsets with a certain number of bands in each subset. Each subset is compared to the next subset using a binary tree grouping algorithm based on correlations of the adjacent spectral bands within each subset. The result is a group of subsets with the reduced number of bands that has as less spectral distortion as possible.

We perform image fusion with two different original HS images. Each original HS image is pre-processed by spectrally integrating over the entire spectral range to obtain a PAN source image that is used in the fusion process. This way, we can eliminate the step of image co-registration since the obtained PAN image is already perfectly aligned to the HS image. Next, we fuse the band-reduced HS image with the PAN image using contourlet-based fusion framework. The resultant fusion image provides enhanced spatial resolution while preserving the spectral information. In order to analyze the band reduction performance, the original HS image is fused with the same PAN image to serve as a reference image, which is then compared to the band-reduced HS image fusion result using eight different quality metrics.

9088-34, Session 7

Determining optimum pixel size for classification

Shawn D. Hunt, Miguel A. Goenaga-Jimenez, Nicole Rodriguez, Univ. de Puerto Rico Mayagüez (United States); Miguel Velez-Reyes, The Univ. of Texas at El Paso (United States)

This work describes a novel method of estimating statistically optimum pixel sizes for classification. Several authors have investigated the relation between pixel size and classification performance, mostly concentrating on percentage of correct classification for the different pixel sizes. Historically more resolution, smaller pixel sizes, are considered better, but this can cause other problems. In addition to the immediate problem of additional data size, having smaller pixels can case difficulties in classification. If the pixel size is too small, then the variation in pixels belonging to the same class could be very large. For example, a grassy area would have very similar pixels if the size is in the tens of centimeters, but would be very different if the pixel size is in the millimeter range. This work studies the variance of the pixels for different pixel sizes to try and answer the question of how small, (or how large) can the pixel size be and still have good algorithm performance. Optimum pixel size is defined here as the size when pixels from the same class statistically come from the same distribution. The work first derives ideal results, then compares this to real data. The real hyperspectral data is from three sources. This includes images from a SOC-700 stand mounted hyperspectral camera, 2m airborne data from an AISA sensor, and space based Hyperion. The results compare the theoretical derivations to variances calculated with real data to estimate different optimal pixel sizes, and show a good correlation between real and ideal data. This work is a step in choosing good pixel sizes when collecting data based on the objects to be classified.

9088-35, Session 8

Particle filter-based spectral unmixing and signature characterization

Sumit Chakravarty, New York Institute of Technology (United States)

Spectral Unmixing is a challenging and absorbing problem. Many avenues of spectral unmixing have been attempted with considerable success. One such avenue is to frame the spectral unmixing problem as an Estimation-Measurement problem and avail the use of the well know Kalman Filter (KF) technique. Two such recent work has been the KF based Linear Unmixing (KFLU) approach and the KF approach for Hyperspectral Signature Estimation, Identification and Abundance Quantification (KFHSE/I/AQ).The above techniques aim to address the spectral unmixing and the spectral signature identification problems respectively.

This work extends the above formulation by the use of Particle Filter(PF) based filtering approach. The particle filter is a recent development int he KF framework. It addresses two major improvements over the KF. It enables use of nonlinearity in the estimation process and further allows fusion of multiple information sources. Additionally, by the use of distributed setup using particles, measurement errors are more efficiently reduced. The above enhancements are the primary motivation of the use of PF for Hyperspectral signature analysis in this paper. A major disadvantage of the PF approach is the high dimensional error issue. We address this problem by an innovative use of the popular Mean -Shift algorithm in the PF framework. experiments performed using this new algorithm demonstrate the utility of the said approach as a new tool to solve the spectral unmixing problem.

9088-36, Session 8

An analysis of the nonlinear spectral mixing of Didymium and soda lime glass beads using hyperspectral imagery (HSI) microscopy

Ronald G. Resmini, The MITRE Corp. (United States); Robert S. Rand, National Geospatial-Intelligence Agency (United States); David W. Allen, National Institute of Standards and Technology (United States); Christopher J. Deloye, The MITRE Corp. (United States)

Nonlinear spectral mixing occurs when materials are intimately mixed. Intimate mixing is a common characteristic of granular materials such as soils. A linear spectral unmixing inversion applied to a nonlinear mixture will yield subpixel abundance estimates that do not equal the true values of the mixture's components. These aspects of spectral mixture analysis theory are well documented. Several methods to invert (and model) nonlinear spectral mixtures have been proposed. Examples include Hapke theory, the extended endmember matrix method, and kernel-based methods. There is, however, a relative paucity of real spectral image data sets that contain well characterized intimate mixtures. To address this, special materials were custom fabricated, mechanically mixed to form intimate mixtures, and measured with a hyperspectral imagery (HSI) microscope. The results of analyses of visible/near-infrared (VNIR; 0.4 micrometers to 0.9 micrometers) HSI microscopy image cubes (in reflectance) of intimate mixtures of the two materials are presented. The materials are spherical beads of didymium glass and soda lime glass both ranging in particle size from 63 micrometers to 125 micrometers. Mixtures are generated by volume and thoroughly mixed mechanically. Three binary mixtures (and the two endmembers) are constructed and emplaced in the wells of a 96-well sample tray: 0%/100%, 25%/75%, 50%/50%, 75%/25%, and 100%/0% didymium/soda lime. Analysis methods are linear spectral unmixing (LSU), LSU applied to reflectance converted to single-scattering albedo (SSA) using Hapke theory, and two kernel-based methods. The first kernel method uses a generalized kernel with a gamma parameter that gauges non-linearity, applying the well-known kernel trick to the least squares formulation of the constrained linear model. This method attempts to determine if each pixel in a scene is linear or non-linear, and adapts to compute a mixture model at each pixel accordingly. The second method uses "K-hype" with a polynomial kernel. LSU applied to the reflectance spectra of the mixtures produced poor abundance estimates regardless of the constraints applied in the inversion. The "K-hype" kernel-based method also produced poor fraction estimates. The best performers were LSU applied to the reflectance spectra converted to SSA using Hapke theory and the gamma parameter kernel-based method.

9088-37, Session 8

Novel metrics to contrast synthetic and real objects in overhead hyperspectral images

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The evaluation of synthetic hyper-spectral images compared to their real optical counterparts is very beneficial. A definition of a concrete discrimination rule is required to improve the generation of these synthetic images. In this paper, we utilized three different metrics such as Gaussian Blur, Differential Operator and singular value decomposition to contrast the synthetic and real objects in overhead hyper-spectral images. The proposed metrics are used to discriminate between pairs of real and synthetic objects such as: cooling units, industrial buildings, houses, conveyors, stacks,

piles, rail lines and ponds. In our approach, we are able to successfully discriminate between the real and synthetic without any apriori knowledge or extra information (e.g., optical flow information) with only a pair of data set for evaluation. We ranked these metrics in their effectiveness in discriminating between synthetic and real images.

9088-38, Session 8

Feature extraction for hyperspectral data using massively parallel graphical processing units

Stefan A. Robila, Montclair State Univ. (United States)

Spectral imaging continues to register an increase in spectral and spatial resolution, as well as in the use of satellite, airborne and land-based platforms, producing tremendous continuous amounts of high-dimensional data that are creating new processing challenges. Most remote sensing techniques suffer from high execution times. They are usually iterative algorithms that have each step's computational complexity dependent on the size of the data. Given the continuous increase in data size, in order for such techniques to remain feasible, one must investigate approaches to speed them up without compromising accuracy. Supported by technological advances, high-performance computing has continuously increased its usability for remote sensing applications.

In this paper we introduce a new group of parallel algorithms for linear unmixing. The focus of the work is on the massive parallelization of recently introduced techniques such as Nonnegative Matrix Factorization (NMF) and implementation on Graphical Processing Units such as NVIDIA's GPU. We first present a theoretical classification of hyperspectral data processing algorithms based on the impact their parallel counterparts have. To support the goal for execution speedup, we focus on the design novel parallel algorithms that maximize data sharing and reduce synchronization needs. We provide an analysis of the newly developed algorithms and show how they are equivalent to their sequential counterparts. Finally, through experimental results using real hyperspectral data and cluster computing architecture we show how the parallel algorithms provide a significant computational speedup compared to the sequential algorithms.

9088-39, Session 8

Integrating spatial information in unmixing using the nonnegative matrix factorization

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An approach to incorporate spatial information in unmixing using the nonnegative matrix factorization is presented. The spatial information is incorporated by partitioning hyperspectral images into spectrally homogeneous regions using quadtree region partitioning. Endmembers for each spatial region are extracted using the nonnegative matrix factorization and then all extracted enmembers for the image are clustered in spectral endmembers classes which better account for the variability of spectral endmembers across the landscape. The paper presents results on the effects of the spectral homogeneity criteria for defining spectrally homogeneous regions. It is found experimentally, that the Shannon entropy produces the best image partitioning when compared to a fine uniform partitioning of the image. Experimental results using AVIRIS data from Indian Pines and Fort AP Hill are used to demonstrate the potential of the proposed approach. These two images were used because of the availability of ground truth for the areas. Unmixing results were evaluated by comparing extracted signatures with published data as well as how abundance maps compare with classification maps for the areas. We also compare obtained results with other approaches published in the literature. Result show that the extracted endmembers signatures and their abundances agree well with published data and that the performance of the approaches is equally or better than published methods. The proposed approach does not assume the presence of pure pixes and lends itself to easy implementation for fully unsupervised unmixing.

9088-40, Session 9

Denoising hyperspectral images for standoff target detection

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Hyperspectral image denoising methods aim to improve the spatial and spectral quality of the image to increase the effectiveness of target detection algorithms. Comparing denoising methods is difficult, because sometimes authors have compared their algorithms to simple methods such as Wiener filter and wavelet thresholding. We would like to compare only the most effective methods for standoff target detection using sampled training spectra. Our overall goal is to implement an HSI algorithm to detect possible weapons and shielding materials in a scene, using a lab collected library of materials spectra.

Selection of a suitable method is based on PSNR, classification accuracy, and time complexity. Since our goal is target detection, classification accuracy is more emphasized; however, an algorithm that requires large processing time would not be effective for the purpose of real-time detection. Elapsed time between HSI data collection and its processing could allow changes or movement in the scene, decreasing the validity of results. Based on our study, the First Order Roughness Penalty algorithm provides computation time of less than 2 seconds, but only provides an overall accuracy of 88% for the Indian Pines dataset. The Spectral Spatial Adaptive Total Variation method increases overall accuracy to almost 97%, but requires a computation time of over 50 seconds. For standoff target detection, Spectral Spatial Adaptive Total Variation is preferable, because it increases the probability of classification. By increasing the percentage of weapons materials that are correctly identified, further actions such as inspection or interception can be determined with confidence.

9088-41, Session 9

Assessment of Schrodinger eigenmaps for target detection

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Non-linear dimensionality reduction methods have been widely applied to hyperspectral imagery due to its structure as the information could be represented in a lower dimension without losing information, and because the non-linear methods preserve the local geometry of the data while the dimension is reduced. One of these methods is Laplacian Eigenmaps (LE), which assumes that the data lies on a low dimensional manifold embedded in a high dimensional space. LE builds a nearest neighbor graph, computes its Laplacian and performs the eigendecomposition of the Laplacian. These eigenfunctions constitute a basis for the lower dimensional space in which the geometry of the manifold is preserved. In addition to the reduction problem, LE has been widely used in tasks such as segmentation, clustering, and classification. In this regard, a new Schrodinger Eigenmaps (SE) method was developed and presented as a semi-supervised classification scheme in order to improve the classification performance and take advantage of the labeled data. SE is an algorithm built upon LE, where the former Laplacian operator is replaced by the Schrodinger operator. The Schrodinger operator includes a potential term V, that taking advantage of the additional information such as labeled data, allows clustering of similar points. In this paper, we explore the idea of using SE in target detection. In this way, we present a framework where the potential term V is defined in diverse forms and the detection performance is evaluated by using different targets

9088-42, Session 9

Hyperspectral band selection using multiple proximity measures and its aggregation for automated target detection

John Ball, Derek T. Anderson, Mississippi State Univ. (United States)

Hyperspectral imagery contains significant spatial and spectral information that can be used to address challenging problems, such as target detection. However, it is often the case that a good number of the bands are highly correlated, which means they contain redundant information. It has been shown that selection of individual bands or groups of bands can significantly improve performance in areas such as target detection. A challenge is numerous measures exist for analyzing the efficacy of hyperspectral bands for similarity (or with simple modifications, dissimilarity) to a known set of target signatures. Furthermore, each measure has particular properties suitable for certain tasks. Examples of common measures include correlation, spectral angle, Jeffreys-Matusita distance, Kullback-Leibler divergence, etc. An important unsolved question is, can multiple measures be combined to improve either the quality or robustness of the band selection, and if so, what combinations would provide an optimal result? This paper examines an optimization strategy based on measures and aggregation for supervised target detection in hyperspectral imagery. Synthetic and real data sets are used, and the proposed method is quantitatively and qualitatively compared to current methods

9088-43, Session 9

Effective training set sampling strategy for SVDD anomaly detection in hyperspectral imagery

Mustafa Ergül, Erman Okman, Nigar Sen, SDT Uzay & Savunma Teknolojileri (Turkey)

Anomaly detection (AD) has recently become an important application for target detection in remotely sensed hyperspectral data. Therefore, variety kinds of methods with different advantages and drawbacks have been proposed for past two decades. Recently, the kernelized support vector data description (SVDD) based anomaly detection approaches become popular as these methods avoid prior assumptions about the distribution of data and provides better generalization to characterize the background. The global SVDD needs a training set for the background modeling; however, it is sensitive to outliers in the data, and so the training set has to be generated with pure background spectra. In general, the training data is selected by random selection of the pixels spectra in entire image. In this study, we propose an approach for better selection of the training data based on principal component analysis (PCA). A valid assumption for remotely sensed images is that the principal components (PCs) with higher variance include substantial amount of background information. For this reason, a subspace composed of several of the highest variance PCs of cluttered data can be defined as background subspace. Thus, with the proposed algorithm, the selection of background pixels is achieved by projecting all pixels in the image into the background subspace and thresholding them with respect to the relative energy on the background subspace. Experimental results verify that the proposed algorithm has promising results in terms of accuracy and speed during detection of anomalies.

9088-44, Session 9

Using mid-infrared reflectance spectra and spatial power spectral density to detect disturbed-earth patches in quartz soils

Richard Fauconier, Precysix, LLC (United States)

A series of experiments was done in which patches of disturbed and undisturbed quartz soils were illuminated by widely tuned quantum cascade lasers in the mid-infrared, and their reflectance spectra analyzed. A small, but persistent and unmistakable twofold effect of digging up the soil was noted, consisting of (1) a general depression of the reflectance amplitude across the entire spectrum and (2) a reduction in the point-to-point spatial variation of features related to the reflectance amplitude. The first component of this effect confirms previous findings of others, and we have found multiple ways to quantify it here in the form of secondary metrics derived from the Christiansen and reststrahlen features of the soil's spectroscopic reflectance; these are straightforwardly related to the physical properties of disturbed and undisturbed earth. Our findings in this regard tend to support the hypothesis that the act of digging up quartz soils throws up fine soil particles which blanket the area surrounding the disturbance epicenter, and scatter incident light more strongly. The second component of the observed twofold effect was quantified by a tertiary metric: the spatial power spectral density (SPSD) of one or more secondary metrics. To forestall confusion, a careful explanation of the SPSD is in order here because in this paper the word "spectrum" is used in two valid senses: a spectroscopic sense and a spatial signal processing sense. The spatial signal is compiled from the spectroscopic measurements, in which the independent variable is the distance of an observed point along the ground from some origin and the dependent variable is the value of the secondary metric at that point. The SPSD is the power spectral density of that spatial signal, as commonly understood in the signal processing community. A practical means (algorithm and device) of exploiting the SPSD, with readily obtainable, completely off-the-shelf components, is proposed.

9088-45, Session 10

Effects of optical aberration on chromotomographic reconstruction

Ryan Tervo, Michael R. Hawks, Glen Perram, Matthew Fickus, Air Force Institute of Technology (United States)

Chromotomography is a form of hyperspectral imaging that utilizes a spinning diffractive element to resolve a rapidly evolving scene that captures both spatial dimensions and the spectral dimension at the same time. Advanced algorithms take the recorded dispersed images and use them to construct the data cube in which each reconstructed image is the recorded scene at a specific wavelength. Varying amounts of optical aberration were introduced into a physics-based model of a chromotomographic imaging system to produce simulated recorded data. Three different tomography algorithms were used to reconstruct the hypercube and the resulting image quality and spectral resolution are compared. The simulated reconstructed images are compared to the experimental results.

9088-46, Session 10

Experimental characterization of the quality of image reconstruction from a chromotomographic system

Kyle Dufaud, Michael R. Hawks, Ryan Tervo, Air Force Institute of Technology (United States)

Chromotomography is a form of hyperspectral imaging that utilizes a spinning diffractive element to resolve a rapidly evolving scene that captures both spatial dimensions and the spectral dimension at the same time. This enables hyperspectral imaging of changing scenes and transient events. Tomographic methods are then used to reconstruct a spectral image cube from the raw data. A chromotomographic system with a spinning direct-vision prism and a high speed camera was used to characterize the quality of the method to create the hyperspectral data cube. Many scenes with varying degrees of spatial, spectral, and temporal complexity were analyzed, including a transient combustion fireball, to assess the degree to which the scene content affects the quality and fidelity of the reconstruction result. Experimental results are discussed, including an analysis of how chromotomography results compare with hypercubes from traditional hyperspectral imagers.

9088-47, Session 10

Characterization and calibration of a compact 6-band multifunctional camera based on patterned spectral filters in the focal plane

Hans Erling Torkildsen, Thomas-Olsvik Opsahl, Trym V. Haavardsholm, Norwegian Defence Research Establishment (Norway); Stephane Nicolas, Norwegian Defense Research Establishment (Norway); Torbjorn Skauli, Norwegian Defence Research Establishment (Norway)

In some applications of multi- or hyperspectral imaging, it is important to have a compact sensor. The most compact spectral imaging sensors are based on spectral filtering in the focal plane. For hyperspectral imaging, it has been proposed to use a "linearly variable" bandpass filter in combination with scanning of the field of view. As the image of a given object in the scene moves across the field of view, it is observed through parts of the filter with varying center wavelength, so that a complete spectrum can be assembled. However if the radiance received from the object varies with viewing angle, or with time, then the reconstructed spectrum will be distorted. We describe a novel camera design where this hyperspectral functionality is traded for multispectral imaging with better spectral integrity. Spectral distortion is minimized by using a patterned filter with 6 bands arranged close together, so that a scene object is seen by each spectral band in rapid succession and with minimal change in viewing angle. The set of 6 bands is repeated 4 times so that the spectral data can be checked for internal consistency. Still the total extent of the filter in the scan direction is small. Therefore the remainder of the image sensor can be used for conventional imaging with potential for using motion tracking and 3D reconstruction to support the spectral imaging function. We show detailed characterization of the camera, including geometrical distortion, point spread function and spectral responsivity. We also discuss strategies for assembling output images with the best possible preservation of information. Example results from 6-band imaging are shown.

9088-48, Session 10

Tower testing of a 64W SWIR supercontinuum laser for use as an HSI illuminator

Joseph Meola, Air Force Research Lab (United States)

Hyperspectral imaging (HSI) systems are currently used for numerous activities related to spectral identifcation of materials. These passive imaging systems rely on naturally refected/emitted radiation as the source of the signal. Thermal infrared systems measure radiation emitted from objects in the scene. As such, they can operate at both day and night. However, visible (VIS) through shortwave infrared (SWIR) systems measure solar illumination refected from objects. As a result, their use is limited to daytime applications. Omni Sciences has produced high powered broadband SWIR super-continuum laser (SSCL) illuminators. A 64-watt breadboard system was recently packaged and tested at Wright-Patterson Air Force Base (WPAFB) to gauge beam quality and to serve as a proof-of-concept for potential use as an illuminator for an HSI receiver. The SSCL was placed in a tower and directed along a 1.4km slant path to various target materials draped over a tilted plywood stand on the ground. The results of this testing are discussed here.

9089-1, Session 1

Robust background modeling for enhancing object tracking in video

Richard J. Wood, John M. Irvine, David Reed, Janet Lepanto, Draper Lab. (United States)

Automated event recognition in video data has numerous practical applications. The ability to recognize events in practice depends on accurate tracking of objects in the video data. Scene complexity has a large effect on tracker performance. Background models can address this problem by providing a good estimate of the image region surrounding the object of interest. However, the utility of the background model depends on accurately representing current imaging conditions. Changing imaging conditions, such as lighting and weather, render the background model inaccurate, degrading the tracker performance. As a preprocessing step, developing a set of robust background models can substantially improve system performance. We present an approach to robustly modeling the background as a function of the data acquisition conditions. We will describe the formulation of these models and discuss model selection in the context of real-time processing. Using results from a recent experiment, we demonstrate empirically the performance benefits from using the robust background modeling.

9089-2, Session 1

Tracking nautical objects in real-time via layered saliency detection

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Traditional motion-based trackers often fail in maritime environments due to a lack of image features to help stabilize video. In this paper, we describe a computationally efficient approach which automatically detects, tracks and classifies different objects within aerial full motion video (FMV) sequences in the maritime domain. A multi-layered saliency detector is utilized to first remove any image regions likely belonging to background categories (ie, calm water) followed-by progressively pruning out distractor categories such as wake, debris, and reflection. This pruning stage combines features generated at the level of each individual pixel, with 2D descriptors formulated around the outputs of prior stages grouped into connected components. Additional false positive reduction is performed via aggregating detector outputs across multiple frames, by formulating object tracks from these detections and, lastly, by classifying the resultant tracks using machine learning techniques. As a by-product, our system also produces image descriptors specific to each individual object, which are useful in later pipeline elements for appearance-based indexing and matching.

9089-3, Session 1

Feature fusion for texture object segmentation in videos

Surya Prasath, Rengarajan V. Pelapur, Kannappan Palaniappan, Univ. of Missouri-Columbia (United States); Gunasekaran Seetharaman, Air Force Research Lab. (United States)

We study an efficient texture segmentation model for multichannel videos using a local feature fitting based active contours scheme. We propose a flexible motion segmentation approach using features computed from texture, intensity components in a globally convex continuous optimization and fusion framework. A fast numerical implementation is described using an efficient dual minimization formulation and experimental results on synthetic and real color videos indicate the superior performance of the proposed method compared to related approaches. The novel contributions include the use of local feature density functions in the context of a luminance-chromaticity decomposition combined with a globally convex active contour variational method to capture texture variations for video object segmentation.

9089-4, Session 1

The effect of state dependent probability of detection in multitarget tracking applications

Amadou Gning, Univ. College London (United Kingdom); W. T. Luke Teacy, Univ. of Southampton (United Kingdom); Rengarajan V. Pelapur, Univ. of Missouri-Columbia (United States); Hadi Aliakbarpour, Univ. College London (United Kingdom); Kannappan Palaniappan, Univ. of Missouri-Columbia (United States); Gunasekaran Seetharaman, Air Force Research Lab. (United States); Simon J. Julier, Univ. College London (United Kingdom)

Multitarget tracking is a key problem in many applications, and as such, has received much attention in the existing literature. However, in general, existing approaches make two basic assumptions: (1) the probability of detecting a target is constant, and (2) the probability of detection is independent over multiple sensor measurements. However, these assumptions are rarely true in practice, because real sensing systems typically produce observations that are highly correlated, and dependent on both the sensor state and other environmental factors. For example, when using computer vision algorithms for detection, the projected size of a target becomes smaller as it moves further from the sensor, causing a decline in the detection probability. Moreover, even if a target is measured, its signature may not be recognised by the detection algorithm; and if the relative position of the target and platform are maintained, this signature will not change and so the target will not become observable.

In this paper, we investigate the impact of these effects on performance, using a PHD-based multi-target tracking algorithm in a simulated urban environment. Specifically, we simulate the motion of an air vehicle sensing the environment using a camera. We compare the performance of a naive model, which assumes independence, to a state dependent model, which has been informed by empirical models of actual sensor and detector behaviour. Our results show that the state dependent model significantly out performs the naïve model, highlighting the importance of modelling such dependencies in future target-tracking algorithms.

9089-5, Session 1

Vehicle change detection from aerial imagery using detection response maps

Zhaohui H. Sun, Mathew Leotta, Kitware Inc. (United States); Anthony J. Hoogs, Kitware, Inc. (United States); Rusty Blue, Kitware Inc. (United States); Robert Neuroth, Juan Vasquez, Air Force Research Lab. (United States); Amitha Perera, Matthew Turek, Kitware Inc. (United States); Erik P. Blasch, Air Force Research Lab. (United States)

Image change detection has long been used to detect significant events in aerial imagery, such as the arrival or departure of vehicles. Usually only the underlying structural changes are of interest, particularly for movable

objects, and the challenge is to differentiate the changes of intelligence value (change detections) from incidental appearance changes (false detections). However, existing methods for automated change detection continue to be challenged by nuisance variations in operating conditions such as sensor (camera exposure, camera viewpoints), targets (occlusions, type), and the environment (illumination, shadows, weather, seasons). To overcome these problems, we propose a novel vehicle change detection method based on the detection response maps (DRM). The detector serves as an advanced filter that normalizes the images being compared specifically for object level change detection (OLCD). In contrast to current methods that compare pixel intensities, the proposed technique is more robust to nuisance changes as variations in image appearance are learned while learning the features of the vehicle detector. We demonstrate the DRM method for detecting vehicles in electro-optical (EO) visual and infrared (IR) imagery.

The proposed DRM approach should work under general collection conditions, with no tasking requirements such as similar viewpoints or times of day. False responses by the detectors in each image are implicitly ignored, as they appear in both images and therefore do not generate change detection. Figure 1 illustrates the proposed DRM-OLCD method. Two images of the same region are captured before and after an event, from the same or different sensors. After spatial registration, the input images are filtered by the vehicle detector, generating response maps that identify local regions with vehicle-like shape, scale, and texture. Object-level changes are detected on the response maps by differencing the likelihood of object presence on the registered maps, followed by thresholding, non-maximum suppression, and post processing. Vehicle detection is not performed explicitly, as thresholding in early stages of processing would reduce sensitivity. Likewise correlation differencing to a terrain map would aid in area selection that segments areas of known nuisances to aid in DRM sensitivity-based refinement to aid users.

9089-7, Session 2

Overview of dynamic data driven applications systems

Erik Blasch, Air Force Research Lab. (United States)

The concept of Dynamic Data-Driven Applications Systems (DDDAS) has been applied to many systems from weather analysis, autonomous vehicles, and cyber networks. In the various applications in the last decade, DDDAS has provided an intersection of modeling, control, measurements, and software for processing large amounts of data for scientific and engineering solutions. In this paper, we organize the various attributes of DDDAS solutions to cover the wide variety of uses for systems designs. The summary of the past and on-going projects demonstrates the applicability of the techniques and solutions that have supported systems designs. Key to these developments are geospatial solutions (e.g., weather), robotics (e.g., vision), and situation awareness that provide big data solution analytics

9089-8, Session 3

Particle filter-based vehicle tracking using fused spatial features and a nonlinear motion model

Raphael Viguier, Kannappan Palaniappan, Univ. of Missouri-Columbia (United States)

Tracking vehicles in aerial wide area imagery is extremely challenging due to the low resolution of targets, the presence of clutter and a large number of distractors, low frame rates of a few hertz (equivalently large vehicle displacements), significant appearance change of the target during tracking and complex backgrounds. Feature-based tracking techniques generate multiple peaks and have difficulty in distinguishing the target from distractors. Consequently, false detections can occur at any time. It is therefore critical to use a motion model in order to eliminate spurious matches, reduce the size of the search region, and at the same time estimate an accurate probability density of the predicted position to improve the target track association. We first tried to take the most advantage of a simple linear motion model, with a Kalman filter-based prediction. Using the prediction error covariance matrix, we are able to eliminate many distractors and to avoid some physically irrelevant jumps in trajectories. However, we also identified the limitations of this approach, in particular for more complex situations such as turns. Therefore, we introduce a particle filter-based non-linear motion model. In the first step of particle filter prediction, we randomly sample small changes in velocity orientation and magnitude. Then the probability map built from the appearance-based features is directly used as a likelihood estimate to update particle weights. After resampling the probability for a point to be chosen as a target location becomes proportional to the initial number of particles on it as much as the feature based similarity with the target template. Finally, we show the results of experiments comparing Features-based only tracking, Kalman filter-based and Particle filter-based.

9089-9, Session 3

Optimal full motion video registration with rigorous error propagation

John T. Dolloff, Peter Doucette, Bryant Hottel, Henry J. Theiss, Glenn Jocher, Integrity Applications, Inc. (United States) and Contractors for The National Geospatial-Intelligence Agency (United States)

No Abstract Available

9089-10, Session 3

Minimum separation vector mapping (MSVM)

Glenn Jocher, John T. Dolloff, Peter Doucette, Bryant Hottel, Henry J. Theiss, Integrity Applications, Inc. (United States) and Contractors for The National Geospatial-Intelligence Agency (United States)

This paper documents our attempts to solve the problem of geo-locating observed image points in a pair of images with moderately well-known camera positions and little else. We approach the problem from a new perspective and develop a robust method designed to work under conditions which traditional Structure From Motion (SFM) techniques tend to fail at. We present our Minimum Separation Vector Mapping (MSVM) approach, and establish the conditions under which it may outperform SFM, as well as some possible failure modes. Lastly, we apply both MSVM and SFM to a real world geo-tagged airborne video and validate the results against surveyed ground truth data.

9089-11, Session 4

Surveillance of ground vehicles for airport security

Erik Blasch, Air Force Research Lab. (United States); Zhonghai Wang, Dan Shen, Intelligent Fusion Technology, Inc. (United States); Haibin Ling, Temple Univ. (United States); Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

Future digital avionics systems will work in complex and cluttered environments which require systems engineering solutions for such applications as airport ground surface management. In this paper, we highlight the use of a L1 video tracker for monitoring activities at an airport. We present methods of information fusion, entity detection, and activity analysis using airport videos for runway detection and terminal events. For coordinated airport security, automated ground surveillance enhances efficient and safe maneuvers for unmanned air vehicles (UAVs) and unmanned ground vehicles (UGVs) operation at airport environments.

9089-12, Session 4

Summary of methods in wide-area motion imagery

Erik Blasch, Air Force Research Lab. (United States); Kannappan Palaniappan, Univ. of Missouri-Columbia (United States); Gunasekaran Seetharaman, Air Force Research Lab. (United States)

In the last decade, there have been numerous developments in wide-area motion imagery (WAMI) from the sensor design to data exploitation. In this paper, we summarize the published literature on the topic in an effort to summarize the techniques, organize the developments, and determine the state-of-the-art. Using the organized summary of developments, we see the variations in approaches and relations to the data sets available. The summary of eth literature provides and anthology of many of the developers in the last decade and their associated techniques. In our use case, we demonstrate the current methods of a contemporary method of WAMI exploitation.

9089-13, Session 5

Automatic georeferencing of imagery from high-resolution, low-altitude, low-cost aerial platforms

Amanda M. Geniviva, Jason Faulring, Carl Salvaggio, Rochester Institute of Technology (United States)

Existing nadir-viewing aerial image databases such as that available on Google Earth contain data from a variety of sources at varying spatial resolutions. Low-cost, low-altitude, high-resolution aerial systems such as unmanned aerial vehicles and balloon-borne systems can provide ancillary data sets providing higher resolution, oblique-looking data to enhance the data available to the user. This imagery is difficult to georeference due to the different projective geometry present in these data. Even if this data is accompanied by metadata from GPS and IMU sensors, the accuracy obtained from low-cost versions of the sensors is limited. Combining automatic image registration techniques with the information provided by the IMU and onboard GPS, it is possible to improve the positioning accuracy of these oblique data sets on the ground plane using existing orthorectified imagery available from sources such as Google Earth. Using both the affine scale-invariant feature transform (ASIFT) and maximally stable extremal regions (MSER) feature detectors aid in automatically detecting correspondences between the obliquely collected images and the base map. These correspondences are used to georeference the high-resolution, oblique image data collected from these low-cost aerial platforms providing the user with an enhanced visualization experience.

9089-14, Session 5

A voxel-based approach for imaging voids in three-dimensional point clouds

Katie N. Salvaggio, Carl Salvaggio, Rochester Institute of Technology (United States)

With recent advances in technologies, reconstructions of three-dimensional (3D) point clouds from multi-view aerial imagery are readily obtainable. However, the fidelity of these point clouds has not been well studied, and voids often exist within the point cloud. Voids in the point cloud are present in texturally flat areas that failed to generate features during the initial stages of reconstruction, as well as areas where multiple views were not obtained during collection or a constant occlusion existed due to collection angles or overlapping scene. A method is presented for identifying the type of void present using a voxel-based approach to partition the 3D space. By using collection geometry and information derived from the point cloud, it is possible to detect unsampled voxels such that voids can be identified. A similar line of sight analysis can then be used to pinpoint locations at aircraft altitude at which the voids in the point clouds could theoretically be imaged, such that the new images can be included in the 3D reconstruction, with the goal of reducing the voids in the point cloud that are a result of lack of coverage. This method has been tested on synthetic image data sets, as well as high-frame-rate oblique aerial imagery captured over Rochester, NY.

9089-15, Session 5

An automated data exploitation system for airborne sensors

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Advanced wide area persistent surveillance (WAPS) sensor systems on manned or unmanned airborne vehicles are critically required for wide-area urban security monitoring to protect our people and warfighter from terrorist attacks. Currently, human (imagery) analysts process huge data collections from full motion video (FMV) for exploitation and analysis (real-time and forensic) providing slow and inaccurate results. An Automated Data Exploitation System (ADES) is urgently needed.

In this paper, we present a recently developed ADES for airborne vehicles under heavy urban background clutter conditions. This system includes 4 processes: (1) fast image registration, stabilization, and mosaicking; (2) advanced non-linear morphological moving target detection; (3) robust multiple target (vehicles, dismounts, and human) tracking (up to 100 target tracks); and (4) moving or static target/object recognition (super-resolution). In the image registration process, an advanced ground corner constellation matching method has been developed that outperforms current-state-of-the-arts, such as SIFT, and Lukas-Kanade algorithm. The multiple target tracking process includes several advanced sub-processes: target size/shape discrimination, adaptive local correlation and search to find undetected targets, and broken track (caused by target occlusion) stitching and association, providing an averaging tracking duration that is about 10 times longer than the current-state-of-the-art tracker. The target/object recognition (super-resolution) process can improve multiple tracked target resolution by 3-5 times without sacrificing large field of view (FOV) coverage. We have also developed processes for robust EO to IR sensor fusion, as well as 2D EO/IR to 3D LiDAR sensor fusion. These multiple sensor fusion processes can significantly reduce false detection rate for improved target recognition, and can also provide reliable geo-registration for the FMV imagery with pin-point targeting capability.

9089-16, Session 5

Large-scale bundle adjustment for wide-area motion imagery (WAMI)

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Camera pose estimation has been explored for the past few decades but still remains an active topic.

Among the existing pose estimation methods, Bundle Adjustment (BA) based approach is robust in terms of obtaining meaningful results even when only partial information is available. BA refers to simultaneously refining camera poses and structures subject to a set of projective constraints.

Normally, in BA after extracting salient features and establishing correspondences, an estimation for rotation and translation, together known as the camera pose, is obtained using either fundamental or homography matrix estimation. Then these initial estimations are used in a triangulation step where the corresponding features are geometrically fused to obtain an initial estimate for the 3D points depicting the structure. Thus, the crucial

part of BA are the optimization and refinement of the initial estimates. Unlike a general BA utilized in other imagery in which there is no metadata (from onboard sensors), in Wide Area Motion Imagery (WAMI) based BA, the camera pose is available. Therefore one can bypass fundamental/homography transformation estimate, however the imperfectness of available metadata (due to noise in sensor measurements) must be taken into the account. As one more difference, in WAMI acquisition the sequence of images is known after they are captured, whereas in a general BA it is not the case. In this work we analyze the effects of position (from GPS) and rotation (from IMU) errors in BA results in terms of accuracy and robustness. We also investigate how choosing a sequence of corresponding features to perform triangulation for obtaining a single 3D point can contribute to the result's precision. This has implications for obtaining robust large scale BA for WAMI based 3D reconstructions.

9089-17, Session 6

Blind restoration of aerial imagery degraded by spatially varying motion blur

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This paper deals with the process of motion blurring in aerial imagery and develops a methodology for blind restoration of spatially varying blur induced by camera motion caused by instabilities of the moving platform. This is a topic of significant relevance with a potential impact on image analysis, characterization and exploitation. A sharp image is beneficial not only from the perspective of visual appeal but also because it forms the basis for applications such as moving object tracking, change detection, and robust feature extraction. The estimated camera motion itself can be exploited as a valuable cue for stabilization. In the presence of general camera motion, the apparent motion of scene points in the image will vary at different locations resulting in space-variant blurring. However, due to the large distances involved in aerial imaging, we show that the blurred image of the ground plane can be expressed as a weighted average of geometrically warped instances of the original focused but unknown image. The weight corresponding to each warp denotes the fraction of the total exposure duration the camera spent in that pose. Given a single motion blurred aerial observation, we propose a scheme to estimate the original focused image affected by arbitrarily-shaped blur kernels. The latent image and its associated warps are estimated by optimizing suitably derived cost functions with judiciously chosen priors within an alternating minimization framework. Several results are given on the challenging VIRAT aerial data set for validation.

9089-18, Session 6

Reference-free multiscale blur detection tool for content-based image retrieval

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Content Based Image Retrieval (CBIR) is a technical area focused on analyzing visual media to answer queries such as "Who, What, and Where,". These images can be captured by common digital devices such as cell phones, laptops, tablets, etc. Therefore, obtaining a metric of the images' quality is an important step in further digital image analysis, semantic assessment, and quality of color, texture, and shape processing. In many existing image quality algorithms, the original image is required as a reference. In this case, Root Mean Square Error (RMSE) and Peak Signal to Noise Ratio (PSNR) can be used to measure the image quality. However, these methods are not valid if there is no available reference image or the image contains blur from motion, compression, or corruption. In our approach, a discrete-wavelet transformation is applied to the blurred image, which decomposes into the approximate image and three detail sub-images, namely horizontal, vertical, and diagonal images. We then focus on noise-measuring the approximate images and blur-measuring the detailed images to assess the image quality. We then compute noise mean and noise ratio from the approximate images, and blur means and blur ratio from the detail co-efficient images. Furthermore, in order to assess the quality of an image we propose a metric incorporating both the blur and noise measurements that is dependent upon unknown parameters estimated via a statistical model that is fit to the training set. The proposed metric is compared to others that have been considered in the literature and can be used in CBIR assessment.

9089-19, Session 6

Efficient feature extraction from wide-area motion imagery by MapReduce in Hadoop

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An increasing amount of large size video data requires a scalable and efficient computer vision framework to solve these problems. A single computer solution is limited in processing power and storage. Current options with the high-performance hardware devices emerge, such as multi-core central processing unit (CPU) and graphics processing unit (GPU) card. A typical example is to develop a distributed application using the message passing interface (MPI). Although multi-core system is powerful, it is complicated to develop Wide-Area Motion Imagery (WAMI) applications using traditional parallel/distributed programming techniques.

Recently, MapReduce technology is popular in both academic and industry community to handle large scale data. One of the main reasons is that there is an open source implementation of Hadoop. MapReduce in Hadoop is a distributed computing paradigm which provides a programming model for analyzing large data sets. MapReduce is based on the observation that large data processing tasks have the same basic structure: a computation is applied over a large number of distributed records to generate partial results, and then combines them to get the final outputs. More specially, there are two important concepts in MapReduce: map and reduce, where a map function processes a key/value pair to generate a set of intermediate key/value pairs; and reduce merges together all intermediate values associated to a given key to yield the final result. In Hadoop framework, the master distribute data into slave node by using map function. Then slave nodes process its own data associated with key value. The intermediate results of each node is then reduced by master to get the final results.

In this paper, the objective is to investigate MapReduce in Hadoop for large scale feature extraction tasks for WAMI. Our motivation is to divide a large size image into several small tiles. The feature extraction of each tile can be distributed to slave nodes in the Hadoop system. After feature extraction of each tile, the overall feature extraction of the large image is obtained by combing these intermediate results of tiles. The input of map in MapReduce is a pair < key, value>, where key is to denote the divided tile of the large image and value is the divided small image. Map function computes the feature extraction of the specified image tile. The reduce function combines the intermediate results of all the map functions and procedures the feature extraction of the large image. Experiments of feature extraction with/without MapReduce are conducted to illustrate the effectiveness of our proposed approach.

9089-20, Session 6

Fast GPU adaptive 3D median filter for motion estimation using background modeling

Mahdieh Poostchi, Kannappan Palaniappan, Univ. of Missouri-Columbia (United States)

Motion detection is often a critical early stage of video object tracking. To

meet the demands of real-time multi-target tracking applications in large high resolution imagery fast parallel algorithms for motion detection are desirable. A common approach is to learn the stationary part of a video sequence using background modeling and detect moving foreground objects using background subtraction.

In terms of background modeling, adaptive 3D spatio-temporal median filter has the advantages in avoiding blending pixel values over other well-known background modeling techniques such as mixture of Gaussians, Kalman filter or Wallflower. The output of the median corresponds to one of the values in the neighborhood and it does not create unrealistic pixel values out of the image content. However, the median operation is computationally expensive which limits its application for real-time, large scale, high resolution imagery.

In our previous work, we have described a parallel 3D spatiotemporal median filter algorithm using the integral histogram as a building block to support adaptive window sizes. The GPU implementation was 60 times faster than the CPU version for a 1Kx1K image reaching 49 fr/sec.

In this paper we explore different techniques to efficiently compute 3D median filter utilizing many core Graphics Processing Unit (GPU) architectures using the CUDA programming model and propose a fast implementation for background estimation model using 3D median filtering for motion detection.

9089-21, Session 6

Comparative analysis of fusion metrics across anomaly detection algorithms

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Detecting anomalies in non-stationary signals has valuable applications in many fields including medicine and meteorology. These include uses such as identifying possible heart conditions from an Electrocardiogram (ECG) signal or predicting earthquakes via seismographic data. The importance of the potential applications of anomaly detection algorithms precipitates the need to compare methods. In this paper, we examine and then compare fusion metrics and fractal/multi-fractal dimension measures over two approaches to anomaly detection. The first approach involves using an artificial neural network to detect anomalies in a wavelet de-noised signal. The other method uses a neural network to analyze an arbitrary number of “perspectives” or transformations of the observed signal for anomalies. Possible perspectives may include wavelet de-noising, Fourier transform, peak-filtering, etc. Fractal geometry and multi-fractal analysis techniques provide a promising approach to analyzing and characterizing non-stationary signals such as seismic signals, ECG, stock prices, etc. Fractal dimension is a measure of complexity as a ratio of change in detail to change in scale and will be used to provide another metric of the anomaly detection algorithms alongside the fusion metrics. The result will rank the metrics based on performance with each anomaly detection method. The paper also serves as a summary of available fusion metrics. The method used in this study could be applied to compare other signal processing algorithms.

9089-22, Session 6

Detection of potential breeding gournds for mosquitoes based on community sourced geo-tagged images

Ankit Agarwal, Usashi Chaudhuri, Subhasis Chaudhuri, Indian Institute of Technology Bombay (India); Gunasekaran Seetharaman, Air Force Research Lab. (United States)

Initiatives have been taken by various government authorities all over the world to involve the citizens in the collection and reporting of data to make better and informed data-driven decisions. Our work shows how the geo-tagged images collected through the general population can be used to combat Malaria and Dengue by identifying localities that contain potential breeding ground of mosquitoes.

Each geo-tagged image received on the server is classified as positive if it is predicted as a potential breeding site for mosquitoes with . We use machine learning to detect whether the image contains either a small stagnant water-body like puddle, or open containers and tyres, bushes etc. We learn this by training an SVM classifier on a histogram-based feature vector obtained after the vector quantization of SIFT features to discriminate the above images from those that contain flowing water, manicured lawns, tyres attached to a vehicle etc.

The geographical region is discretized into a rectangular array points at an appropriate resolution. Each image’s probability of being a mosquito breeding site is assigned to the discretized point nearest to its geo-tagged location. A geographical heatmap is generated after convolving the above array with a Gaussian kernel with an appropriate variance, providing the likelihood of a location being tagged as a possible breeding ground of mosquitoes. The heatmap thus generated can be used by concerned health authorities to take appropriate action and to promote civic awareness.

In this paper we shall explain in details the methodology adopted and results of simulation studies over a large number of crowd sourced images.

9089-23, Session 6

Wavelet-based polarimetry analysis

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Wavelet transformations have become a promising approach in the field of image and signal processing. A wavelet is a waveform of effectively limited duration that has an average value of zero. Wavelet analysis is done by breaking up the signal into shifted and scaled versions of the original signal. The key advantage of wavelets is that they are capable of revealing smaller changes, trends, and breakpoints that are missed by other techniques such as the common Fourier analysis. The phenomenon of polarization is a useful for target detection and tracking. For example, Long Wave Infrared (LWIR) polarization is beneficial for detecting camouflaged objects and can distinguish between man-made objects from natural clutter. In addition, the Stokes Polarization Parameters, which are calculated from 0°, 45°, 90°, 135°, right circular, and left circular intensity measurements, provide spatial orientations of target features and suppress natural features. In this paper, we propose a wavelet based method to analyze Long Wave Infrared Polarimetry Imagery to discriminate targets such as dismounts and vehicles from background clutter. These parameters can be used for thresholding, segmentation, and material classification. Experimental results show this method is effective and can be used in a wide range of applications such as change detection, shape extraction, target recognition, and feature-aided tracking.

9089-24, Session 7

Computer vision-based technologies and commercial best practices for the advancement of the motion imagery tradecraft

Marja Phipps, 2d3 Inc. (United States); David Capel, 2D3 Ltd. (United States); James R. Srinivasan, 2d3 Inc. (United Kingdom)

Motion imagery capabilities within the Department of Defense/Intelligence Community (DoD/IC) have advanced significantly over the last decade, attempting to meet continuously growing data collection, video processing and analytical demands in operationally challenging environments. The motion imagery tradecraft has evolved accordingly, enabling teams of analysts to effectively exploit data and generate intelligence reports across multiple phases in structured Full Motion Video (FMV) Processing Exploitation and Dissemination (PED) cells. Yet now the operational requirements are drastically changing. The exponential growth in motion imagery data continues but to this the community adds multi-INT data, interoperability with existing and emerging systems, expanded data access, non-traditional users, collaboration, automation, and support for ad hoc configurations beyond the current FMV PED cells. To break from the legacy system lifecycle, we look towards a technology application and commercial adoption model course which will meet these future Intelligence, Surveillance and Reconnaissance (ISR) challenges. In this paper, we explore the application of cutting edge computer vision technology to meet existing FMV PED shortfalls and address future capability gaps. For example, real-time georegistration services developed from computer-vision-based feature tracking, multiple-view geometry, and statistical methods allow the fusion of motion imagery with other georeferenced information sources - providing unparalleled situational awareness. We then describe how these motion imagery capabilities may be readily deployed in a dynamically integrated analytical environment; employing an extensible framework, leveraging scalable enterprise-wide infrastructure and following commercial best practices.

9089-25, Session 7

A multimodal, activity-based intelligence experiment using motion imagery sensors

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The current development of sensor technology is leading to higher frame rates and higher ground sampling distances. This inherently assumes that greater temporal and spatial resolutions, respectively, will allow intelligence analysts to better perceive activities in motion imagery. This experiment is designed to dispel said notion, by using a series of multimodal sensors at varying frame rates to characterize activities of interest within a given scene. The modalities include thermal, multispectral, polarimetric, and panchromatic sensors. Our experiment took place at the Chester F. Carlson Center for Imaging Science (CIS), Rochester Institute of Technology (RIT). 15 participants were asked to execute a series of directions on the ground, while being filmed from multiple cameras mounted on the roof. These actions were designed to mimic common activities of interest, including: exchanging objects, entering/exiting vehicles, and engaging in group sports. The entirety of the collection took approximately two minutes. Since the premise of this research is to link technology development to an image analyst's ability to characterize activities in motion imagery, we pursued multimodal augmentation as a substitute for increasing temporal/spatial resolutions. We used a Go-Pro 3 as the basic sensing platform and plan to use the thermal, multispectral, and polarimetric data to enhance an automated activity recognition algorithm. The high number of modalities in this experiment required the use of three separate sensing platforms. Each platform was operating at a different frame rate, with the lowest and highest at 6Hz and 60Hz respectively. Temporal registration was performing via a series of blinking LEDs in view of all three-sensor platforms.

9089-27, Session 7

Full-motion video analysis for improved gender classification using non-pathological gait kinematics

Jeffrey B. Flora, Khan M. Iftekharuddin, Old Dominion Univ. (United States); Darrell F. Lochtefeld, Air Force Research Lab. (United States)

Gender classification using a human subject's natural motion has applications in human-computer interface, ergonomics, medical diagnosis and rehabilitation, and surveillance. In this paper, we exploit significant body parts indicators obtained from analyzing non- pathological gait kinematics to improve the gender classification for larger datasets with subjects moving in a less controlled environment. Experimental testing with fifty subjects reveals that human gender classification rates using leave-one-out cross-validation are improved from 73% to 89%.

9089-28, Session 7

Standardized rendering from IR surveillance motion imagery

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Defense and law enforcement increasingly make use of video from commercial surveillance systems owned by non-government entities. Making upgraded imaging technology available to commercial users at cost-effective prices would benefit all parties. Thermal infrared imagers offer substantial benefits over near-infrared capability. IR&D results are shared to encourage government support for commercial IR motion imagery.

Thermal IR structural analysis provides highly accurate and reliable identification of human faces. Consistent vascular patterns are extracted from different cameras in both MWIR and LWIR, as demonstrated by extensive testing under NIST sponsorship. Key to structural analysis is the use of 3D modeling to achieve standardized poses. Key to integrating thermal IR surveillance into established systems based on visible light imagery is the use of composite IR/VL.

Face renderings generated from composite imagery have the appearance of detailed artist sketches. The rendering process removes the impact of dim lighting and increases distinction of persons with very dark skin.

Model standardization is based on orientations of structural components. Frontal images are not required, nor are the appearance of both eyes. Density and complexity of structural features facilitates model aggregation over long image sequences, intermittent appearances, and changes in distance and orientation. To the extent a model is complete, its rotation can produce full or partial renderings from the perspective of an eyewitness, 2D reference image, or another surveillance camera. Rendering facilitates recognition by human observers, and enables integration with automated systems based upon visible light imagery.

9089-29, Session 7

Lambda vision

Michael F. Czajkowski, Lockheed Martin Corp. (United States)

There is an explosion in the quantity and quality of IMINT data being captured in ISR today. While automated exploitation techniques involving computer vision are arriving, only a few architectures can manage both the storage and bandwidth of large volumes of IMINT data and also present results to analysts quickly. At Lockheed Martin's Advanced Technology Laboratories we have been actively researching in the area of applying computer vision to Big Data cloud computing. In this paper, we present the results of our work in adopting a Lambda Architecture to process and disseminate IMINT data using computer vision algorithms. Our approach embodies an end-to-end solution by processing IMINT data from sensors to serving information products quickly to analysts, independent of the size of the data. Our solution lies in dividing up the architecture into a speed layer for low-latent processing and a batch layer for quality answers at the expense of time, but in a robust and fault-tolerant way. We tested our approach using a large corpus of IMINT data collected by a C-130 Shadow Harvest sensor over Afghanistan from 2010 through 2012. This corpus included full motion video from both narrow and wide area field of views. We evaluated our work on a scaled-out cloud infrastructure that is similar in composition to INSCOM's Red Disk and NSA's GHOSTMACHINE. We show experimental results to prove the scalability of our architecture and precision of its results using a computer vision algorithm designed to identify man-made objects in sparse data terrain

9089-30, Session 7

Improved target recognition using dedicated video architecture: meet CHARM

Gordon A. Cain, Vision4ce Ltd. (United Kingdom)

The CHARM is a new generation multi-function video processor and tracker, which extends current state of the art performance in a size weight and power optimized package. Traditional tracking systems are not designed to process high definition video sensors. Many tracking solutions require that the video be windowed or subsampled down to standard definition sizes and frames rates, losing any advantage the high definition video provided. To fully exploit high definition video tracking potential, we have developed a system with a dedicated video architecture that processes full high definition video and tracks multiple targets in real time with minimal latency. A wide range of high bandwidth digital video interfaces can be accommodated including CameraLink and HD-SDI. In this paper, we discuss our multi-core coherent software structured approach, which includes several automatic configuration functions to reduce integration time and complexity with a consequential cost saving. We also discuss how the CHARM can be integrated effectively into a dynamic closed-loop control application.

9089-31, Session 7

Statistical moments-based methods for detecting sub-pixel target tracks in large-image sequences

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This paper reviews and compares the performance of several methods to detect target tracks in image sequences. The targets are assumed to be sub-pixel, i.e. is not resolved by the imaging system, and moving over a static background. An electro-optical imaging system is modeled by an optics and motion jitter time dependent point-spread-function. The focal plane is assumed to contain of a large number detectors with non-uniform gain and offsets, contain a fraction of dead and saturated pixels and Gaussian noise. To process the resulting large amount of data requires simple, fast and robust processing methods to quickly find and display tracks of moving targets in a single image. Simple methods imply few and "cheap" operations that can easily be accomplished without using complex numerical techniques or complex signal processing. Fast methods imply that the algorithm can be performed in parallel, possibly using graphical processing units (GPU). Robust implies that the resulting output is not very sensitive to detector problems such as non-responsive or "happy" pixels and image clutter from pointing errors and/or scene changes such as moving clouds. Several methods for detecting tracks were investigated, e.g. range-invariant anomaly detection, Reed-Xiaoli anomaly detection, and cumulative pulse matching and statistical moments. Among them the third and fourth moment method seemed to perform quite well. A literature search showed that higher order moments are not commonly used as anomaly detectors even though their interpretation would suggest such a use. Probability distributions of noise in imaging systems tends to follow a Gaussian distribution which results in zero values for the third and fourth moments. An object moving through a pixel in a scene will momentarily perturb the pixel intensity signal, introducing a change of both skewness (third moment) and kurtosis (fourth moment) in the intensity histogram relative to an undisturbed pixel. The skewness (third moment) describes the symmetry of the probability distribution with positive values indicating a positively skewed distribution which results when a pulse with positive amplitude is added to noise. The kurtosis describes how fast the probability distribution falls off and for the case that a target is present creates an outlier that will increase the kurtosis.

9089-32, Session 7

Aerial video georegistration using terrain models from dense and coherent stereo matching

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In the context of aerial imagery, one of the first steps toward a coherent processing of the information contained in multiple images is georegistration, which consists in assigning geographic 3D coordinates to the pixels of the image. This enables accurate alignment and geopositioning of multiple images, detection of moving objects and fusion of data acquired from multiple sensors. To solve this problem there are different approaches that require, in addition to a precise characterization of the camera sensor, high resolution referenced images or terrain elevation models, which are usually not publicly available or out of date. Building upon the idea of developing technology that does not need a reference terrain elevation model (LaTourette and Pritt 2012), we propose a georegistration technique that applies variational methods to obtain a dense and coherent surface elevation model that is used to replace the reference model. The surface elevation model is built by interpolation of scattered 3D points, which are obtained in a two-step process following a classical stereo pipeline: first, coherent disparity maps between image pairs of a video sequence are estimated and then image point correspondences are back-projected. The proposed variational method enforces continuity of the disparity map not only along epipolar lines (as done by previous georegistration techniques) but also across them, in the full 2D image domain. In the experiments, aerial images from real video sequences have been used to validate the proposed technique.

9089-33, Session 7

Low-complexity multiplierless DCT/DST approximations for low-power HEVC digital IP cores

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Image and video compression plays a major role in multimedia transmission. Specifically the discrete cosine transform (DCT) is the key tool employed in a vast variety of compression standards such as H.265/HEVC due to its remarkable energy compaction properties. Rapid growth in digital imaging applications, such as multimedia and automatic surveillance that operates with limited bandwidths has led to extensive development of video processing systems. For defense applications including UAV and space-based imaging systems, the use of low-complexity algorithms and low-power circuits is of paramount importance due to constraints in weight and available power. Algorithms that offer high video quality at high compression while consuming minimal resources in terms of circuit real estate and power consumption are therefore desired for video imaging and remote sensing applications. For image and video compression, efficient DCT approximations that have very low arithmetic complexity is a way to respond to such demands. From this standpoint, the main objective of the proposed work is to introduce a new DCT approximation equipped with a fast algorithm which requires only fourteen addition operations and zero multipliers or bit-shifting operations leading to significant reductions in chip area and power consumption compared to conventional DCT algorithms such as the Arai/Chen algorithms. We provide complete design details for several k x k, k=4,8,16,32,64 blocked 2-D algorithms for multiplierless DCT/DST computation with video evaluation using HEVC real-time software encoder. Custom digital architectures are proposed, simulated, implemented on Xilinx FPGAs and verified in conjunction with software models.The paper will include sections describing the proposed method, implementation steps, and simulation results, insight into custom VLSI/FPGA trade-offs and the trade-off between video quality, compression level, circuit complexity, reconfigurability and power consumption. The proposed multiplierless DCT approximation have important applications in a range of critical imaging systems that can be based on the H.264/AVC, H.265/HEVC and similar standards.

9090-1, Session 1

Unification of automatic target tracking and automatic target recognition

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The subject being addressed is how an automatic target tracker (ATT) and an automatic target recognizer (ATR) can be fused together so tightly and so well that their distinctiveness becomes lost in the merger. This has historically not been the case outside of biology and a few academic papers.

The biological model of ATT/ATR arises from dynamic patterns of activity distributed across many neural circuits and structures (including retina). The information that the brain receives from the eyes is "old news" at the time that it receives it. The eyes and brain forecast a tracked object's future position, rather than relying on received retinal position. Anticipation of the next moment – building up a consistent perception – is accomplished under difficult conditions: motion (eyes, head, body, scene background, target) and processing limitations (neural noise, delays, eye jitter, distractions). Not only does the human vision system surmount these problems, but it has innate mechanisms to exploit motion in support of target detection and classification.

Biological vision doesn't normally operate on snapshots or frames of imagery. Feature extraction, detection and recognition are spatiotemporal. When vision is viewed as a spatiotemporal process, target detection, recognition, tracking, event detection and activity recognition, do not seem as distinct as they are in current ATT and ATR designs. They appear as similar mechanism taking place at varying time scales. A framework is provided for unifying ATT and ATR.

9090-2, Session 1

Optimized sparse presentation-based classification with position-weighted block dictionary

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This paper is aiming at applying sparse representation based classification (SRC) on a certain scale. Having analyzed the characteristics of object recognition, authors have proposed a position-weighted block dictionary (PWBD) and design a framework of SRC with it (PWBD-SRC). After analyzing the characteristics of general object recognition and the principle of the classifier of SRC method further, authors optimize the method with Maximum Likelihood Estimation (MLE) and propose the optimized PWBD-SRC method. Principle and implementation of the optimized PWBD-SRC have been introduced in the article, and experiments on car model, Yale and AR face database have been given in the article. From experimental results, it can be seen that optimized PWBD-SRC works well than the original method.

9090-3, Session 1

Maritime vessel recognition in degraded satellite imagery

Katie Rainey, Shibin Parameswaran, Josh Harguess, Space and Naval Warfare Systems Ctr. Pacific (United States)

Automated vessel classification algorithms are relevant to many military and security applications. The RAPid Image Exploitation Resource (RAPIER) developed by Space and Naval Warfare (SPAWAR) Systems Center Pacific (SSC Pacific), provides automated ship detection in overhead satellite imagery as well as in full-motion video from unmanned aerial systems in support of image analysts. RAPIER returns ship detects in the form of small images chipped out of a larger video or satellite image. Algorithms to recognize the ship class or type of each image chip are necessary to provide increased functionality to RAPIER and greater benefit to the analyst.

Object recognition in a maritime setting poses challenges not faced by other recognition problems. While ships often stand out from the dark ocean background, images may be cluttered or obscured by clouds, white caps, wakes, piers, or land. There may also be significant visual variation within ship classes, as ship type is determined by the ship's function rather than its physical appearance. Successful recognition algorithms in other applications often rely on the availability of sufficient training data -- i.e., a face recognition system may require multiple training images of each face appearing under multiple poses or lighting conditions. Collecting comparable data sets of ocean vessels is practically impossible. Thus ship classification algorithms must be robust to the variations present in ocean imagery and must be flexible enough to be trainable with limited data.

Given the difficulties in acquiring sufficient maritime imagery to train statistical recognition algorithms, it is important that classification methods be able to function accurately on data even if it has been degraded or was not collected under the same conditions as the training data. This new work considers the effectiveness of a support vector machine (SVM) classifier and bag-of-visual-words image representations -- a method previously identified to be successful on ship imagery -- on ship data that has been intentionally degraded in one of the following ways: downsampled to a lower resolution; corrupted with random noise; or partially occluded. These three methods of data degradation are representative of challenges faced in real-world applications; sensors collect at varying resolutions, images can become noisy through transfer or due to the collection scenario, and targets are frequently occluded by clouds or other objects.

In addition to testing on degraded data sets, this work will compare several options for construction bag-of-visual-words descriptions of ship images and test their effectiveness when fed into an SVM classifier. Bag-of-visual-words is a method of combining local features into a single image representation vector. The local feature types which will be compared are the scale invariant feature transform (SIFT) and two variants on SIFT, RootSIFT and PHOW. The relative merits of these methods will be evaluated in the context of the ship data set and its degraded forms.

9090-4, Session 1

Application of an image feature network-based object recognition algorithm to aircraft detection and classification

Jeremy Straub, The Univ. of North Dakota (United States)

A network created from the distance-values representing the spacing between points identified by an image feature detection algorithm can be utilized for object classification. This approach, which is both scale and rotation agnostic, has applicability to many different application domains. Those where it may be particularly effective have characteristics such as object presence being unknown and applications where the object may be presented at different distances (or captured with imaging hardware of various resolutions) and where its orientation in the object is unknown, a priori. This algorithm scales the network, normalizing it to the pre-identified patterns that will be used for comparison purposes and then compares the networks, determining (first) the most likely match and (then) whether the correlation between the sensed and pre-identified patterns is sufficient to make a classification assertion.

This paper presents work on the application of this algorithm to the problem of aircraft presence detection and classification. First, an overview of the operation of the algorithm is presented. Then, modifications required for it to work for aircraft classification are discussed. Performance under an ideal case is characterized. Next, the paper considers algorithm performance across a variety of scenarios, including instances where the background

(sky) has different characteristics (e.g., cloud versus no clouds, different lighting levels, different meteorological phenomena), detection and characterization from different levels of image resolution and detection and characterization where multiple craft are present in a single frame. An extension to the base algorithm, which determines the orientation of a detected aircraft is also presented.

9090-5, Session 1

Fusion-based approach for long-range night-time facial recognition

Robert B. Martin, Mikhail Sluch, Kristopher M. Kafka, Andrew Dolby, Robert V. Ice, Brian E. Lemoff, West Virginia High Technology Consortium Foundation (United States)

Long range identification using facial recognition is being pursued as a valuable surveillance tool. The capability to perform this task covertly and in total darkness greatly enhances the operator's ability to maintain a large distance between themselves and a possible hostile target. An active-short-wave-infrared (SWIR) video imaging system has been developed to produce high-quality long-range night/day facial imagery for this purpose. Most facial recognition techniques match a single input probe image against a gallery of possible match candidates. When resolution, wavelength, and uncontrolled conditions reduce the accuracy of single-image matching, multiple probe images of the same subject can be matched to the watch-list and the results fused to increase accuracy. If multiple probe images are acquired from video over a short period of time, the high correlation between the images tends to produce similar matching results, reducing the benefit of the fusion. In contrast, fusing matching results from multiple images acquired over a longer period of time, where the images show more variability, produces a more accurate result. Image variables include pose angle, field-of-view, lighting condition, facial expression, target to sensor distance, contrast, and image background. Long-range SWIR video was used to generate probe image datasets containing different levels of variability. Face matching results for each image in each dataset were fused, and the results compared. Datasets containing higher levels of variability resulted in more accurate fused match results.

9090-30, Session 1

Demonstration of a 100 x 100 wide field of view camera with integrated high-resolution, 25X foveated zoom

Aaron L. Birkbeck, Eliseo Ranalli, Robert E. Saperstein, Patrick C. Mock, Anis Husain, Ziva Corp. (United States)

Ziva Corporation's FOveated VISion (FOVIS) camera is a uniquely designed 100°x100° wide field of view (WFOV) camera that incorporates adaptive wavefront correction which enables high resolution, real time optical foveation and zoom on one or multiple targets in the WFOV while simultaneously providing situational awareness of the entire scene. Emulating the foveated vision capability of raptors, the dual imager FOVIS camera design contains two optical paths, where one is dedicated to a WFOV perspective and the other a high resolution, magnified zoom capable of resolving and identifying targets located anywhere in the field of regard (FOR). Target selection in the FOR is accomplished with a custom designed fast steering mirror (FSM) whose 2-D, ±10° angular scans span the entire 100°?100° WFOV. Immediately following the FSM is an integrated deformable mirror (DM) that provides an adaptive correction surface that eliminates the aberrations inherent in the WFOV optics and enhances the foveated zoom resolution. Furthermore, Ziva has adapted its proprietary computational imaging for aberrated optics (CIAO) software algorithm to work with the FOVIS camera prototype and effectively limit the necessary wavefront correction provided by the DM to just focus (single element DM) and thereby significantly reduce cost and complexity.

9090-6, Session 2

Detection of moving targets in homogeneous clutter by MIMO radar systems employing the generalized detector

Vyacheslav P. Tuzlukov, Kyungpook National Univ. (Korea, Republic of)

In this paper, we consider a multiple-input multiple-output (MIMO) radar approach employing widely dispersed transmit and receive antennas for the detection of moving targets based on implementation of the generalized detector. The MIMO radar transmits orthogonal waveforms from the different transmit antennas so these waveforms can be separated at each receive antenna. For a moving target in colored Gaussian noise-plus-clutter, we quantify the gains from having widely dispersed antennas that allow the overall system to observe the target simultaneously from several different directions. The MIMO radar performance is contrasted with that of a traditional phased-array approach, which employs closely spaced antennas for this purpose. The MIMO radar approach is well studied to handle targets that have small radial velocities for scenarios in which collocated sensors cannot separate the target from the background clutter. Both a centralized processing and a simple distributed processing from of the MIMO radar approach are developed and studied, and the gains from the centralized version, which come at the price of additional complexity, are clearly demonstrated and explained intuitively. The constant false alarm rate (CFAR) property of an adaptive version of the MIMO moving target generalized detector is also demonstrated for homogeneous clutter. Comparative analysis of MIMO radar detection performance shows a superiority of employment of the generalized detector in comparison with conventional ones.

9090-7, Session 2

Evolution of nonstationary noise in waveguides

Leon Cohen, Jonatan Ben-Benjaming, Hunter College (United States)

The basic ideas of noise have been developed for the stationary noise case, where the statistical quantities do not change in time or in space. However, there exist many situations, where the noise changes in both space and time (reverberation noise for example). Of particular importance is noise in a waveguide with dispersion where noise may evolve significantly in space and time. We discuss the mathematical characterization of non-stationary noise with particular emphases on explicit models such as the two-plate waveguide. We derive explicit formulas for the evolution of the autocorrelation function and study under what conditions it evolves to a stationary situation.

9090-8, Session 2

Detection, characterization, and localization of multiple LFMCW LPI signals

Brandon Hamschin, John Clancy, Mike Grabbe, Matthew Fortier, Johns Hopkins Univ. Applied Physics Lab. (United States); Johns Novak, ASD Space and Sensor Systems (United States)

In this paper a method for passive Detection, Characterization, and Localization (DCL) of multiple LPI signals is described that meets this new demand. In contrast to other detection and characterization approaches, such as those based on the Wigner-Ville Hough Transform (WVHT), our approach does not begin with a parametric model of the received signal, specified directly in terms of its LFMCW constituents. Rather, we analyze the signal over time intervals that are short, non-overlapping, and contiguous by modeling it within these intervals as a sum of sinusoids (i.e., harmonics) with unknown frequencies, deterministic but unknown amplitudes,

unknown order (i.e., number of harmonic components), and unknown noise autocorrelation function. Using this Short- Time Harmonic Model (STHM) of the signal, we develop a detection statistic and associated threshold that is a function of False Alarm Probability PFA and not a function of the noise properties. Doing so we reliably detect the presence of multiple LFMCW signals in colored noise without the need for prewhitening, efficiently estimate (i.e., characterize) their parameters, provide estimation error variances for a subset of these parameters, and produce Time-of-Arrival (TOA) estimates that can be used to estimate the geographical location of (i.e., localize) each LFMCW source. Finally, by using the entire time-series we refine these parameter estimates by using them as initial conditions to the Maximum Likelihood Estimator (MLE), which was found to be computationally infeasible for multiple LFMCW signals if accurate initial conditions were not available to limit the search space. We demonstrate the performance of our approach via simulation, wherein we use a link budget analysis to determine Signal-to-Noise Ratio (SNR) as a function of the distance between the LPI transmitter and the passive ELINT receiver for transmitter power levels on the order of 1 Watt and for reasonable receiver characteristics.

To summarize, the most salient features of our work that are absent from any single approach in the literature are:

1) no calibration is necessary, either in-situ or in the laboratory, to determine detection threshold settings as a function of Probability of False Alarm (PFA);

2) one does not need to assume the system noise present in the received time-series is white or has a known autocorrelation function, thereby eliminating the need for prewhitening;

3) environments with multiple, simultaneous (a/k/a co-channel) signals can be treated without adding a stifling computational burden;

4) direct recognition of the number of signals in the environment is achieved vice an iterative approach;

5) in addition to estimates of the parameters that define the instantaneous frequency of each LFMCW signal, our approach produces estimates of the variance of a subset of these parameters directly from the data;

6) estimates of the Time-of-Arrival (TOA) of each LFMCW signal are obtained, which can be used to localize each LFMCW source if three or more stationary ELINT receivers are present, or if two or more moving receivers are available with synchronized clocks.

9090-10, Session 3

New experiments in inverse synthetic aperture radar image exploitation for maritime surveillance

Firooz A. Sadjadi, Lockheed Martin Advanced Technology Labs. (United States)

This paper provides a summary of recent experimental study in using signatures obtained via polarimetric inverse synthetic aperture radar (ISAR) for classification of small boats in littoral environments. First step in discerning the intention of any small boat is to classify and fingerprint it so it can be observed over an extended period of time. Currently, ISAR techniques are used for large ship classification. Large ships tend to have a rich set of discernible features making classification straightforward. However, small boats rarely have a rich set of discernible features, and are more vulnerable to motion-based range migration that leads to severe signature blurring, thus making classification more challenging. The emphasis of this paper is on the development and use of several enhancement methods for polarimetric ISAR imagery of small boats.

9090-11, Session 3

Ladar ATR via probabilistic open set techniques

Matthew Scherreik, Brian D. Rigling, Wright State Univ. (United States)

Target recognition algorithms trained using finite sets of target and confuser data result in classifiers limited by the training set. Algorithms trained under closed set assumptions do not account for the infinite universe of confusers found in practice. In contrast, classification algorithms developed under open set assumptions label inputs not present in the training data as unknown instead of assigning the most likely class. We present an approach to open set recognition that utilizes class posterior estimates to determine probability thresholds for classification. This is accomplished by first training a support vector machine (SVM) in a 1-vs-all configuration on a training dataset containing only target classes. A validation set containing only class data belonging to the training set is used to iteratively determine appropriate posterior probability thresholds for each target class. The testing dataset, which contains targets present in the training data as well as several confuser classes, is first classified by the 1-vs-all SVM. If the estimated posterior for an input falls below the threshold, the target is labeled as unknown; otherwise it is labeled with the class resulting from the SVM decision. We apply our method to automatic target recognition (ATR) of ladar range images and compare its performance to current open set and closed set recognition techniques.

9090-12, Session 3

Radar target identification using various nearest neighbor techniques

Ismail I. Jouny, Lafayette College (United States)

Radar target identification using decision-theoretic nonparametric distance based methods such as the nearest neighbor techniques have long been used for classifying unknown non-cooperative radar targets using their backscatter Radar Cross Section (RCS) data. This study revisits this subject using the recently developed Large Margin Nearest Neighbor (LMNN) technique which was developed by Weinberger et al. LMNN have had notable successes in recognizing large-vocabulary images in addition to other significant applications. The radar target recognition problem (assuming coherent radar measurements) has been defined by two performance limiting issues namely 1) azimuth ambiguity (and/or erroneous estimation of target azimuth) and 2) presence of extraneous scatterers along the target or within its range. Furthermore, distance based techniques are optimal when additive noise is white Gaussian which is not often the case. This study examines these different scenarios and highlights any of the benefits that LMNN may add to the radar target classification problem. The distance-based method adopted here is tested using real radar target models of commercial aircraft with backscatter recorded in a compact range. The results are compared with the statistical optimal solution (Bayesian based) when it exists and with the traditional k-NN technique. Scenarios such as various additive noise statistics, presence of extraneous scatterers, azimuth ambiguity and azimuth misinformation are considered, and scenarios involving partial scatterer absence are considered.

9090-13, Session 3

Automatic detection of pulsed radiofrequency (RF) targets using sparse representations in under-complete learned dictionaries

Daniela I. Moody, David A. Smith, Steven P. Brumby, Los Alamos National Lab. (United States)

Automatic classification of transitory or pulsed radio frequency (RF) signals is of particular interest in persistent surveillance and remote sensing applications. Such transients are often acquired in noisy, cluttered environments, and may be characterized by complex or unknown analytical models. Conventional representations using orthogonal bases, e.g., Short Time Fourier and Wavelet Transforms, can be suboptimal for classification of transients, as they provide a rigid tiling of the time-frequency space, and are not specifically designed for a particular target signal. They do not usually lead to sparse decompositions, and require separate feature selection algorithms, creating additional computational overhead. We

propose a fast, adaptive classification approach based on non-analytical dictionaries learned from data. Our goal is to detect chirped pulses from a model target emitter in poor signal-to-noise and varying levels of simulated background clutter conditions. This paper builds on our previous RF classification work, and extends it to more complex target and background scenarios. We use a Hebbian rule to learn discriminative RF dictionaries directly from data, without relying on analytic constraints or additional knowledge about the signal characteristics. A pursuit search is used over the learned dictionaries to generate sparse classification features in order to identify time windows containing a target pulse. We demonstrate that learned dictionary techniques are highly suitable for pulsed RF analysis and present results with varying background clutter and noise levels. The target classification decision is obtained in almost real-time via a parallel, vectorized implementation.

9090-14, Session 3

Autonomous underwater pipeline monitoring navigation system

Nina Mahmoudian, Byrel Mitchell, Guy Meadows, Michigan Tech (United States)

The big picture goal is to create an autonomous inspection system to facilitate more efficient and frequent means to document pipeline conditions. Enbridge Inc., operates a pair of 20-inch diameter, underwater pipelines which cross the Straits of Mackinac, approximately half mile west of the bridge. The aim of this project is to develop autonomous motion-control and navigation algorithms for a UUV – The Ocean Server IVER3 – to track long linear features such as underwater pipelines. As part of this work, the Nonlinear and Autonomous Systems Laboratory (NAS lab) is developing algorithms that utilize inputs from the vehicle's state of the art sensor package, which includes digital imaging, digital 3-D Side Scan Sonar, and Acoustic Doppler Current Profilers. The resulting algorithms should tolerate "real-world" waterway with episodic strong currents, low visibility, high sediment content, a variety of small and large vessel traffic.

9090-15, Session 4

Time-frequency filtering for classifying targets in nonstationary clutter *(Invited Paper)*

Patrick J. Loughlin, Vikram T. Gomatam, Univ. of Pittsburgh (United States)

Automatic target recognition in active sonar operations is adversely impacted by induced noise, namely the reflections of the transmitted sonar signal from non-target objects in the channel (i.e., reverberation and clutter). While increased transmit energy will improve performance against independent additive noise, it will not help with induced noise. Moreover, the induced noise is inherently nonstationary. Accordingly, framing the problem in the joint time-frequency domain may provide insights into detection and classification of targets in clutter. We analyze a standard model of clutter consisting of the sum of reflections from random point scatterers, to show how the nonstationarities of clutter are manifest in the time-frequency and ambiguity function domains. We also examine different time-frequency based classification architectures and present simulation results for classifying targets in clutter.

9090-16, Session 4

The Wigner-Hilbert transform

Patrick J. Loughlin, Univ. of Pittsburgh (United States)

The concept of "instantaneous frequency" arose from observations of sounds that changed their pitch over time, vibrations of changing rate, and light of changing color, among other natural and man-made situations. While the physical phenomenon was clear, a formal mathematical description of instantaneous frequency was not, and there are many different "instantaneous frequencies" that can be associated with the same real signal. Gabor gave a procedure for obtaining a particular instantaneous frequency by associating a specific complex signal, called the analytic signal, to the given real signal, from which follows a unique definition for the amplitude and phase (and hence the instantaneous frequency as the derivative of the phase). Gabor obtained the analytic signal by inverting the Fourier spectrum of the real signal over the positive frequency range only, resulting in a complex signal whose real and imaginary parts form a Hilbert transform pair. Many other different procedures have been developed before and since, yet Gabor's analytic signal representation and the Hilbert transform are ubiquitous today in many areas of science and engineering.

Given the prominent role that the Wigner distribution has played in studying signals with changing frequencies, we introduce a new transform and complex signal representation by applying Gabor's idea to the Wigner distribution. The real and imaginary parts of the resulting complex representation are related by what we define as the Wigner-Hilbert transform. We show that the Wigner-Hilbert transform may be interpreted as a signal-dependent Hilbert transform. We examine properties of the resulting complex signal, which we call the Wigner-Gabor signal, and give examples and comparisons to the analytic signal. In general the Wigner-Gabor complex signal is different from the analytic signal, except for the case of a pure tone.

9090-17, Session 4

Optimal power allocation and limited-feedback strategies for distributed classification in wireless sensor networks *(Invited Paper)*

Mohammad Fanaei, Natalia A. Schmid, Matthew C. Valenti, Marwan M. Alkhweldi, West Virginia Univ. (United States)

This paper investigates the problem of distributed multi-hypothesis classification in the context of wireless sensor networks (WSNs). Spatially distributed sensors make noisy observations about an underlying hypothesis to be classified. Each sensor will then make a (potentially faulty) binary decision regarding the existence or absence of one of the possible hypotheses. This local binary decision is sent to a central entity in the WSN, known as the fusion center (FC), through parallel channels corrupted by fading and additive noise. The FC combines the set of received locally processed signals to form a decision metric that is then used to classify the underlying hypothesis. Two problems of finding optimal quantization thresholds at local sensors and deriving an optimal power-allocation scheme are considered in order to minimize the probability of misclassification at the FC, given a constraint on the maximum total transmit power in the entire network. As will be shown, the optimal local transmit power assigned to each sensor depends on the individual channel gains. In order to alleviate the requirement of feeding the instantaneous channel-fading gains from the FC back to local sensors, a limited- feedback scheme is proposed based on the generalized Lloyd quantization algorithm. Numerical results show the effectiveness of optimal binary quantizer design and optimal power allocation on the global misclassification probability at the FC, and will also demonstrate that the effect of limited feedback of channel-fading gains on the global system performance is negligible, despite providing a drastic bandwidth conservation.

9090-9, Session 5A

Cross-spectral TDOA and FDOA estimation *(Invited Paper)*

Douglas J. Nelson, National Security Agency (United States)

We present methods for accurately estimating and tracking instantaneous frequency of narrowband signal components and the relative time delay of a signal received by two receivers. These methods are applied to the problem of estimating the location of an emitter from the signal(s) received by one

or more receivers. Both instantaneous frequency estimation and time delay estimation are based on previously reported cross-spectral methods that have been applied successfully to a variety of signal processing problems. Frequency estimation is accomplished by differentiating the phase of the short time Fourier transform (STFT) with respect to time to create a cross-spectral (CS) surface. Frequency tracking is accomplished by applying LaGrange interpolation to the signal frequency recovered from the phase of the CS surface. Time delay estimation is accomplished by applying cross-spectral-like methods to the the spectra of the received signals, resulting in a significant accuracy improvement over conventional correlation.

The methods presented may be used to accurately geolocate an emitter from as few as a single moving receiver. For the single receiver case, geolocation is accomplished by matching the Doppler characteristics of the received signal to the Doppler characteristics computed from potential emitter locations and the receiver motion. If the signal is received simultaneously by two or more receivers, the methods presented may be used to accurately estimate time difference of arrival (TDOA) and accurately estimate and track the instantaneous frequency difference of arrival (FDOA) of the received signals. These methods improve TDOA and FDOA based geolocation performance of conventional cross-ambiguity function (CAF) geolocation processes.

9090-21, Session 5A

Matrix superposition structure with tree-based principle *(Invited Paper)*

Andre U. Sokolnikov, Visual Solutions and Applications (United States)

If we assume that a natural image can be modeled as a succession of a multilevel system, we can develop an optimal routine of a matrix superposition. Each matrix separates the fundamental elements by a set of optimal criteria. The matrix superposition is then characterized by a tree-based principle which is applied adaptively. We will also demonstrate how the missing data constrains may be overcome by collecting additional measurements.

9090-18, Session 5

Classification-based target tracker using convolutional neural networks with GPU implementation

Serhat Ozdemir, ASELSAN Inc. (Turkey); Ozgur Yilmaz, Turgut Ozal Univ. (Turkey)

We present the GPU implementation of a novel classification based target tracking algorithm that uses convolutional neural networks with pre-training. Single layer neural network algorithm learns receptive fields of hidden layer neurons through clustering. The algorithm first extracts random patches from unlabeled training images in an unsupervised manner, normalizes and whitens them. K-means clustering is used to assign receptive fields that can also be viewed as the members of a dictionary of visual “words”. The receptive fields resemble Gabor filters which are widely used to model simple neurons in the visual cortex. Linear combination of these visual words uniquely and sparsely represents each patch. Image regions are encoded by the Gabor filter-like representation of their patches through spatial pooling. After spatial pooling, a feature vector is computed for the image region of interest.

The target tracking algorithm utilizes the neural network for detecting the location of learned target in the image. The learning algorithm is initialized with a database of images that belong to target-background binary classes. In order to enforce robustness, instead of single image, multiple (pixel shifted) target and background images are cropped and feature vectors are extracted. A linear SVM classifier is trained using these target and background feature vectors. The SVM classifier is used to detect and localize target images. The overall motion of the target is estimated by the motion of target images. The classifier is trained during tracking to adjust to appearance changes in the target. There are also control mechanisms during this online training that will abort in case of occlusions or clutter. In order to reduce drifts and jumps due to appearance similarities in the background, pixel clustering mechanisms are utilized and the pixel cluster that is closest to the last known location of the target is accepted and the rest of the target detections are rejected. The algorithm is tested on publicly available datasets and is shown to outperform existing algorithms in terms of tracking error and robustness. Integral image implementation, feature extraction and classification stages of the algorithm have been implemented on the GPU and run in real-time.

9090-19, Session 5

Sparse representation for vehicle recognition

Nathan D. Monnig, Univ. of Colorado at Boulder (United States); Wesam A. Sakla, Air Force Research Lab. (United States)

The Sparse Representation for Classification (SRC) algorithm has been demonstrated to be a state-of-the-art algorithm for facial recognition applications. Wright et al demonstrate that under certain conditions, the SRC algorithm classification performance is agnostic to choice of linear feature space, and highly resilient to image corruption. In this work, we examined the SRC algorithm performance on the vehicle recognition application, using images from the semi-synthetic vehicle database generated by the Air Force Research Laboratory. To represent modern operating conditions, vehicle images were corrupted with noise, blurring, and occlusion, with representation of varying pose and lighting conditions. Experiments suggest that linear feature space selection is important, particularly in the cases involving corrupted images. Overall, the SRC algorithm consistently outperforms a standard k nearest neighbor classifier on the vehicle identification task.

9090-20, Session 5

Adaptive compressive sensing for target detection

Abhijit Mahalanobis, Lockheed Martin Missiles and Fire Control (United States)

In this paper, we discuss a compressive sensing techniques for target detection that dramatically reduce the number of measurements that are required to perform the task, as compared to the number of pixels in the conventional images.. Specifically, we discuss a two-stage approach that fist adaptively searches a large area using shift-invariant masks to determine the locations of potential targets (i.e. the regions of interest), and then re-visits each location to discriminate between target and clutter using a different set of specialized masks. We show that the overall process is not only highly efficient (i.e dramatically reduces the number of measurements as compared to the number of pixels), but does so without appreciable loss in target detection performance.

9090-22, Session 5

Automatic target recognition using group-structured sparse representation

Bo Sun, Xuewen Wu, Jun He, Xiaoming Zhu, Beijing Normal Univ. (China); Chao Chen, Naval Academy of Armament (China)

Sparse representation theory has been increasingly used in the fields of pattern analysis and machine learning, due to its robustness to corruption and occlusion, and little dependence on the features etc. However, most of the existing sparse classification methods intend to look for the sparsest representation of a test sample y in the overcomplete dictionary D, y=Dx, where x is a sparse vector whose non-zero entries identify the input y, which

do not explicitly take the hidden structure in the dictionary into account. The traditional sparse coding models are not efficient to classification task. In a general classification task, the dictionary of the training data has a group structure where a few groups of the dictionary elements correspond to the training data in each class. Thus, we cast the classification as a group-structured sparse representation problem where our goal is to find a representation of a test sample that involves the minimum number of groups from dictionary. We formulate this problem using a non-convex sparsity-inducing regularization optimization. Then, we relax the non-convex optimization to a convex version which can be solved by group lasso. To evaluate the proposed algorithms, we build an automatic target recognition framework based on sparse representation which can perform automatic target detection and recognition. We present several experiments on natural vehicles and faces images database. The experimental results show that the proposed approach improves the recognition rate of standard sparse models, and our system can efficiently and effectively recognize targets under a variety of realistic conditions, especially, where the desired features of the sparse representation based classification method are kept.

9090-23, Session 6

Automatic recognition of emotions from facial expressions

Henry Xue, Izidor Gertner, The City College of New York (United States)

In the human-computer interaction (HCI) process it is desirable to have an artificial intelligent (AI) system that can identify and categorize human emotions from facial expressions. Such systems can be used in security, in entertainment industries, and also to study visual perception, social interactions and disorders (e.g. schizophrenia and autism). In this work we survey and compare the performance of different feature extraction algorithms and classification schemes. We introduce a faster feature extraction method that resizes and applies a set of filters to raw images. In addition, we extend SVM to multiple dimensions while still maintaining high accuracy rate of the classification. The algorithms were tested using the Japanese Female Facial Expression (JAFFE) Database, and The Database of Faces (AT&T Faces).

9090-24, Session 6

Robust person and object tracking in LWIR and VIS based on a new template matching method

Thomas Müller, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Template matching is one of the oldest techniques in computer vision. It has been applied in a variety of different applications using cross correlation as distance measurement or derivates of it. But so far, the success of object tracking is very limited despite the promising structural similarity search that is done thereby. Based on an analysis of the underlying reasons, a new kind of measurement is proposed therefore to open up far more of the potential the structural search inherently offers. This new measurement does not sum up differences in color space like the cross correlation but outputs the number of matching pixels in percent. As a key feature, local color variations are considered in order to properly handle the different character of homogeneous and highly structured regions and to model the relations between them. Furthermore, relevant differences between templates are expatiated and stressed while irrelevant contributions to the measurement function are widely suppressed in order to avoid unnecessary distortions on the measurement and, therefore, on the search decision. The presented results document the advantages in comparison to the measurements known from the literature. Different objects

and persons in LWIR and VIS image sequences are tracked to illustrate the performance and the benefit in a broad field of applications.

9090-25, Session 6

Estimation of human emotion using fusion of visual and thermal infrared imagery

Hung Nguyen, Kazunori Kotani, Fan Chen, Japan Advanced Institute of Science and Technology (Japan); Bac Le, Univ. of Science, Ho Chi Minh City (Viet Nam)

In recent years, automated estimation of human emotion has attracted the interest of many researchers, because such systems will have numerous applications in security, medicine, and especially human-robot interaction. Many previous works proposed have been inclined towards developing facial emotion estimation. Nevertheless, there is a lack of accurate and robust facial emotion estimation methods to be deployed in uncontrolled environments. When the lighting is dim or when it does not uniformly illuminate the face, the accuracy decreases considerably. Moreover, human emotion estimation based on only the visible spectrum has proved to be difficult in cases where there are emotion changes that expressions do not show. Using thermal infrared (IR) imagery is a new and innovative way which is not sensitive to light conditions, to fill the gaps in the human emotion estimation field. Besides, human emotions could be manifested by changing temperature of face skin which is obtained by an IR camera. Consequently, thermal infrared imagery gives us more information to help us robustly estimate human emotions.

Although there are many significant advantages when we use IR imagery, it has several drawbacks. Firstly, thermal data are subjected to change together with body temperature caused by variable ambient temperatures. Secondly, presence of eyeglasses may result in loss of useful information around the eyes. Glass is opaque to IR, and object made of glass act as temperature screen, completely occluding the parts located behind them. Hence, the sensitivity of IR imagery is decreased by facial occlusions. Thirdly, there are some facial regions not receptive to the emotion changes. To eliminate the effects of the three challenging problems above, we propose using fusion model from visible information and thermal information. From visible information, we obtain the co-ordinates of eyes, mouth. Using the co-ordinates, based on thermal information, we extract the thermal region of interest (t-ROI) around eye regions, check-bone regions, mouth regions, nose regions and forehead regions. The obtained regions will be inputs for estimating human emotion. We will also reduce the impact of ambient temperature by normalizing it between different frames. To estimate seven emotions, we use three conventional methods Principal Component Analysis (PCA), Eigen-space Method based on class-features (EMC), Multiple Discriminant Analysis (MDA) and PCA-EMC, PCA-MDA to extract feature vectors and then find the similarity between the testing data and training data. The Kotani Thermal Facial Emotion (KTFE) database will be used for testing.

9090-26, Session 6

Military personnel recognition system using texture, colour, and SURF features

Martins E. Irhebhude, Eran A. Edirisinghe, Loughborough Univ. (United Kingdom)

This paper presents an automatic, machine vision based, military personnel identification and classification system. Classification is done using a Support Vector Machine (SVM) on sets of Army, Air Force and Navy camouflage uniform personnel datasets. In the proposed system, the arm of service of personnel is recognised by the camouflage of a person's uniform, type of cap and the type of badge/logo. The detailed analysis done include; camouflage cap and plain cap differentiation using gray level co-occurrence matrix (GLCM) texture feature; classification on Army, Air Force and Navy camouflaged uniforms using GLCM texture and colour histogram bin features; plain cap badge classification into Army, Air Force and Navy using Speed Up Robust Feature (SURF). The proposed method recognised camouflage personnel arm of service on sets of data retrieved from google images and selected military websites. Correlation-based Feature Selection (CFS) was used to improve recognition and reduce dimensionality, thereby speeding the classification process. With this method success rates recorded during the analysis include 91.9% for camouflage appearance category, 100%, 90% and 100% rates of plain cap and camouflage cap categories for Army, Air Force and Navy categories, respectively. Accurate recognition was recorded using SURF for the plain cap badge category. Substantial analysis has been carried out and results prove that the proposed method can correctly classify military personnel into various arms of service. We show that the proposed method can be integrated into a face recognition system, which will recognise personnel in addition to determining the arm of service which the personnel belong. Such a system can be used to enhance the security of a military base or facility.

9090-27, Session Posters-Tuesday

Image feature extraction based multiple ant colonies cooperation

Zhang Zhilong, Jicheng Li, Xinping Lu, National Univ. of Defense Technology (China)

This paper presents a novel feature extraction method for remote sensing imagery based on multi ant colony cooperation. Firstly, multi-resolution expression of the input remote sensing imagery is created, and two different ant colonies are spread on different resolution images. The ant colony in the low resolution image uses phase congruency as their inspiration information, the ant colony in the high resolution image use gradient magnitude as their inspiration information. This two ant colonies cooperate to find features in the image through sharing the same pheromone matrix. At last, image features are extracted based on threshold the pheromone matrix. As ant colony algorithm has the characteristic of parallelity, the computing efficiency of this method is very high. At the same time, since much information of the input image are used as inspiration information of the ants, the method shows higher intelligence and robustness in feature extracting process than other simple edge detectors.

9090-28, Session Posters-Tuesday

Fast algorithm of infrared small target detection in jitter background

Weiping Yang, Xinping Lu, Jicheng Li, National Univ. of Defense Technology (China); Zhongliang Jiang, National Univ. of Defence Technology (China)

In the high technical local battles, it is required that the weapon system must have a fast reaction, a long detection distance, namely, the system must detect the target at a long distance in the real-time warfare. The target image is of a small size with only one or few pixel's area while the interferences of noise and clutter background remain strong. Therefore, the detection of small low signal_ to_ noise targets becomes a hot and difficult task. After analyzing infrared small targets, noise and clutter model, we use a small window median filter to estimate the infrared background. Then using background cancelling method, that is, subtracting the estimated background from the source image, the resident image can be obtained. Finally, an adaptive threshold is used to segment the resident image to obtain the potential targets. Considering the computational load, the two-dimensional filter is simplified into a one-dimensional filter. Experimental results show that the algorithm achieved good performance and satisfy the requirement of big size image's real-time processing.

9090-29, Session Posters-Tuesday

Polarization diversity sensor for enhanced detection and tracking

David B. Chenault, Art Lompado, Jonathan Hanks, Richard Edmondson, Polaris Sensor Technologies, Inc. (United States)

Polarization diversity results from differences in surface temperature, roughness, material properties, aspect angle to the sensor, sky down-welling and background radiance reflecting from the target. Often times, the polarization signature resulting from this diversity enhances the detection of manmade targets in a confounding background. Furthermore, that difference is often present even when the thermal signature of the same target blends into the background. This paper will demonstrate improvements in detection and tracking of of several target sets representing ground and maritime target polarization signatures over conventional signatures.

9090-31, Session Posters-Tuesday

Line fitting-based feature extraction for object recognition

Bing Li, Lockheed Martin Systems Integration-Owego (United States)

Image feature extraction plays a significant role in image based pattern applications. There are three types of features: global, local, and hierarchical. Global features, such as Fourier descriptors and moment invariants, are calculated from an entire image. They extract global characteristics and are usually robust to small changes of pixel values. However, they are difficult to cover local characteristics and therefore only have limited use in high performance systems. Local features, such as local moments and gradient features, are extracted by dividing an image into small regions and calculating features in each region. Local features overcome the drawback of global features and are able to capture local characteristics but, they are not able to obtain global characteristics. Hierarchical features, such as wavelet features, are extracted by representing an image as a pyramid and computing features in each layer. Features in high layers (low resolution) represent global characteristics while those in low layers extract local characteristics. However, in the wavelet approach different regions of the image are treated with the same weight and divided equally into sub-regions regardless of the amount of information of in each region. This causes inefficient feature representation since the features are wasted in the homogeneous regions where no information exists.

In this paper, we propose a new approach to generate hierarchical features. This new approach applies line fitting to adaptively divide regions based upon the amount of information and creates line fitting features for each subsequent region. It overcomes the feature wasting drawback of the wavelet based approach and demonstrates high performance in real applications. For gray scale images, we propose a diffusion equation approach to segment an image into positive energy, negative energy and zero-energy areas. The information of this image is mainly concentrated in the non-zero energy area. From this segmentation we generate the positive energy and negative energy map images. After positive and negative map images are generated, we propose a line fitting approach to divide regions recursively and create features for each region simultaneously. This new feature extraction approach is similar to wavelet based hierarchical feature extraction in that high layer features represent global characteristics and low layer features represent local characteristics. However, the new approach uses line fitting to adaptively focus on information-rich regions so that we avoid the feature waste problems of the wavelet approach in homogeneous regions. In order to reduce the computational cost, we propose a moment based method to extract features and demonstrate that the computational cost of the new approach, O(N) with N pixels, is lower than wavelet transform, O(NlogN). Finally, the experiments for handwriting word recognition show that the new method provides higher performance than our original handwriting word recognition approach.

9091-1, Session 1

Determining sensor location from measured state and covariance of tracked objects

Lynn R. Purser, Georgia Tech Research Institute (United States)

Radars are designed to track objects in space and report those objects' positions, velocities and measurement uncertainties. Sometimes due to political sensitivity radar locations are not made known to allies even though the entities may share track reports. The question arises can these radar reports be viewed the other way around, that is, could the reports be utilized to find the reporting radar's location? Further suppose that disparately located radars track a common object. These reports are fused in order to gain a more robust scene of the tracked objects. Can fused reports be utilized to discover the locations of the contributing radars? And last, if the answers to these questions are true then can the positions of the radars be obfuscated or even in order that their location(s) cannot be ascertained?

Given a radar's measurement state and the associated filter covariance of a tracked object, a parameteric line is shown to exist that connects the

measured object track to the radar. From this line the reporting radar's latitude and longitude is easily determined. Fused track states from pairs of radars share a parametric plane that intersects the earth between the location of the contributing radars yielding a method to determine the location of both radar locations. By adjusting the direction cosines via the eigenvector of the minimum eigenvalue the radar's location can be hidden or even spoofed.

9091-2, Session 1

Study of data fusion algorithms applied to unattended ground sensor network

Benjamin Pannetier, Jean Dezert, Julien Moras, ONERA (France)

In this paper, data obtained from wireless unattended ground sensor network are used for tracking multiple ground targets (vehicles, pedestrians and animals) moving on and off the road network. The goal of the study is to evaluate several data fusion algorithms to select the best approach to establish the tactical situational awareness. The ground sensor network is composed of heterogeneous sensors (optronic, radar, seismic, acoustic, magnetic sensors) and data fusion nodes. The fusion nodes are small hardware platforms placed on the surveillance area that communicate together. In order to satisfy operational needs and the limited communication bandwidth between the nodes, we study several data fusion algorithms to track and classify targets in real time. A multiple targets tracking (MTT) algorithm is integrated in each data fusion node taking into account embedded constraint. The choice of the MTT algorithm is motivated by the limit of the chosen technology. In the fusion nodes, the distributed MTT algorithm exploits the road network information in order to constrain the multiple dynamic models. Then, a variable structure interacting multiple model (VS-IMM) is adapted with the road network topology. This algorithm is well-known in centralized architecture, but it implies a modification of other data fusion algorithms to preserve the performances of the tracking under constraint. Based on such VS-IMM MTT algorithm, we adapt classical data fusion techniques to make it working in three architectures: centralized, distributed and hierarchical. The sensors measurements are considered asynchronous, but the fusion steps are synchronized on all sensors. Performances of data fusion algorithms are evaluated using simulated data and also validated on real data. The scenarios under analysis contain multiple targets with close and crossing trajectories involving data association uncertainties.

9091-3, Session 1

Summary of tracking and identification methods

Erik Blasch, Air Force Research Lab. (United States); Chun Yang, Sigtem Technology, Inc. (United States); Ivan Kadar, Interlink Systems Sciences, Inc. (United States)

Over the last two decades, many solutions have arisen to combine target tracking estimation with classification methods. Target tracking includes developments from linear to non-linear and Gaussian to non-Gaussian processing. Pattern recognition includes detection, recognition, classification, and identification methods. Integrating tracking and pattern recognition has resulted in numerous approaches and this paper seeks to organize the various approaches. In a use case, we provide a comparative example of some of the methods for performance analysis.

9091-4, Session 1

Fusing airborne video with RF location estimates to locate moving emitters in dense mover environments

Robert Cole, Geoffrey Guisewite, Herbert G. Greene, Raytheon Intelligence & Information Systems (United States)

Moving emitters in dense environments present challenges for conventional signal based location estimation. The emergence of wide field of view, high resolution, persistent EO imaging from airborne sensors introduces the possibility of a multi-INT approach via video-RF data fusion. Video based object extraction techniques can identify moving objects with very high spatial precision; precision that can be leveraged to locate moving emitters if a means of associating extracted movers to observed signal transmissions can be demonstrated. To examine the feasibility of improving emitter location estimates in this manner, we conducted a study in which we correlated simulated video tracks with location estimates produced from signal measurements.. To this end, we generated vehicle movement over a known road network using varying levels of mover density. Signal transmissions were generated using several different levels of ambient noise and interference. These transmissions were associated to video tracks using a fusion algorithm that employed a model derived from the physical structure of the scene to re-interpret the signal observations under constraints imposed by the video tracks and the RF pathways. Our results suggest that with only a few signal observations from a given moving emitter, the associated mover can be identified at a low error rate even at low signal to noise ratios that normally produce extremely high levels of location estimate uncertainty.

9091-5, Session 1

Optimal fusion of video and RF data for detection and tracking with object occlusion

Benjamin Shapo, Christopher Kreucher, Integrity Applications, Inc. (United States)

The image processing community has recently shown great interest in algorithms for detecting and following objects in video. Investigators have adopted many feature-based approaches to tracking in video data including using primitive geometric shapes as features, segmenting objects into individual features, and multi-timescale techniques for feature association.

An important problem in video surveillance is occlusion between the imaging source and the object, which can lead to missed detections, dropped tracks, and mis-classification. Some investigators address this

occlusion problem by fusing data from multiple sensors. This approach is advantageous because it can provide more information than each individual sensor alone. Traditionally, multisensor fusion performs tracking at each sensor and then associates tracks across sensors. This track-before-fuse method may be necessary in systems that have limited processing or communication capabilities. However, because hard tracking decisions occur at each sensor, this approach may not achieve optimal performance.

In the image processing community, multisensor fusion has focused almost exclusively on using multiple video cameras, or employed data from different spectral bands. However, the work described in this paper is based on the premise that fusing data from heterogeneous sensors can provide more robust detection and tracking performance than fusing data from homogeneous sensors. For example, video may be severely degraded at night or by rain, whereas RF is not affected by these conditions. Furthermore, rather than an approach that performs the tracking function at each sensor and then fuses the results, this paper advocates a fuse-before-track approach that performs data fusion before declaring tracks.

Our work differs from previous efforts in several ways, including our use of RF to provide more sensing diversity and our fuse-before-track approach that differs from commonly-used association-based approaches.

This paper presents two main contributions. First, we show how the fuse-before-track approach naturally admits heterogeneous sensors and supports optimal Bayesian estimation. Second, we illustrate the approach with an experiment using a combination of an imaging sensor and a multistiatic RF array. The experiment includes severe sensor occlusion, generating a case where conventional track-and-then-fuse approaches fail.

9091-7, Session 2

Recognition of ships for long-term tracking

Sebastiaan P. van den Broek, Henri Bouma, Henny Veerman, Koen W. Benoist, Piet B. W. Schwering, TNO Defence, Security and Safety (Netherlands)

Long-term tracking is important for maritime situational awareness to identify currently observed ships as earlier encounters. In cases of, for example, piracy and smuggling, past location and behavior analysis are useful to determine whether a ship is of interest. Furthermore, it is beneficial to make this assessment with sensors (such as cameras) at a distance, to avoid costs of bringing an own asset closer to the ship for verification. The emphasis of the research presented in this paper, is on the use of several feature extraction and matching methods for recognizing ships from electro-optical imagery within different categories of vessels. One of the used features is SIFT, which previously was shown to be useful in discriminating between small ships, even at low resolution in infrared imagery. From an assessment on imagery of ships, an indication of discriminative power is obtained between and within different categories of ships. This is used to assess the usefulness in persistent tracking, from short intervals (track improvement) to larger intervals (re-identifying ships). The result of this assessment on real data is used in a simulation environment to determine how track continuity is improved. In this simulator observation of ships from operational navy assets is modeled, with the distinction probabilities used to model differences between ships.

9091-8, Session 2

Real-time target tracking for a 360-degree panoramic IR imager

Colin C. Olson, U.S. Naval Research Lab. (United States) and Sotera Defense Solutions, Inc. (United States); Jonathan M. Nichols, James R. Waterman, U.S. Naval Research Lab. (United States)

We introduce a tracking algorithm for high-clutter maritime applications such as those found in harbors and riverine waterways. The algorithm combines correlation- and model-based tracking in a manner that is robust to occluding clutter without the need for a separate collision prediction module. A movement model is used to center a weight distribution relative to a larger correlation region which contains the last known target position—algorithm characteristics which are robust to changes in direction and orientation. Occlusions are automatically handled by a memory model that stores a long-term aggregation of previous target examples—an important feature in cluttered maritime scenes with many slow-moving targets. Target queuing is based on the detection of persistent moving edges using a wavelet model. Large data rates associated with the panoramic imager necessitate the use of parallel computation on graphics processing units. We discuss the queuing and tracking algorithms as well as practical considerations required for real-time implementation.

9091-9, Session 2

Clutter heterogeneity and ground moving target indication tracking

Bhashyam Balaji, Christoph Gierull, Defence Research and Development Canada (Canada)

The ground moving target indication (GMTI) problem is the detection of slow ground-moving targets from an airborne or spaceborne platform. This necessitates adaptive multichannel signal processing techniques, such as space-time adaptive processing (STAP) or synthetic aperture radar (SAR) MTI. The signal processing outputs as well as probability of detection (Pd) and probability of false alarm (Pfa), are then the inputs to a tracker.

The performance of a GMTI tracker is a function of the parameter estimation quality in the detection step, that can be bounded via Cramer-Rao bounds (CRBs) that can be calculated for single as well as multichannel radars. Similarly, there exists extensive body of research on single receiver channel analysis for computing the receiver operator characteristic (ROC) curve (Pd vs Pfa). However, this is inadequate for GMTI applications that necessarily requires a multichannel system.

In recent work, robust and relatively simple-to-implement analytical formulas for computing the ROC curves for multichannel radars. These can be computed for any GMTI radars under fairly general assumptions for the interfering clutter and desired target signal statistics. The approach expands the well-published single receiver channel analysis to multichannel approaches, such as the displaced phase centre antenna (DPCA) or space-time adaptive processing (STAP). The derivation comprises a flexible modelling approach permitting solutions for a variety of target models including deterministic targets and the fluctuating target Radar Cross Section (RCS) Swerling target models. The approach additionally allows for the averaging of multiple independent measurements (multi-looking).

In this paper, this novel ROC curve computation is used in assessing the impact of multichannel system performance and clutter heterogeneity on GMTI tracking. Specifically, clutter heterogeneity (e.g., for urban environment) can be modelled in terms of a texture random variable leading to the product or compound model for clutter, and this has been validated in numerous examples. From the aforementioned results, the Pds and Pfas for clutter with varying levels of heterogeneity are computed and used in generating more realistic simulated tracking scenarios. The performance of the tracking algorithms, and performance of tracker compared to that without this knowledge, and the improvement in tracker performance is quantified in terms of standard measures of performance.

9091-10, Session 2

Magnetic dipole tracking and smoothing

Bhashyam Balaji, J. B. Nelson, Defence Research and Development Canada (Canada)

The magnetic signature of a ferromagnet at large distances can be modelled as a magnetic dipole. This induces an anomaly in the ambient Earth magnetic field. By using magnetic sensors (magnetometers), it is possible to measure some function of the magnetic signature as a function of time. A scalar magnetometer measures the overall magnitude of the field, including the contribution of the ambient Earth magnetic field. The vector

magnetometer measures the three components of the magnetic field, while the magnetic tensor gradiometer measure the spatial gradient of the field components. Provided the SNR is large enough, it is possible to detect and localize the dipole using techniques such as the orthonormal basis function decomposition method and the high-order crossing method.

The measured magnetic signatures are functions of the relative position, velocity, and magnetic moment vector of the target. This leads one to consider the problem in terms of the Bayesian state vector, assuming one knows the function(s) that relate the measured magnetic signature to the unknowns. In prior work (Birsan), a Bayesian formulation was provided and solutions using standard filtering techniques (such as unscented Kalman filter and particle filter) for the situation of stationary sensors and a moving target.

However, the targets were assumed to be non-manoeuvering and/or single dynamical models, and it was assumed that there were no false alarms.

In this paper, we investigate the performance of the interacting multiple model for a manoeuvering dipole target whose signature is measured from a moving platform equipped with a scalar magnetometer. In this case magnetic noise from platform motions or the underlying geology can add false alarms. That is, these sources produce real magnetic anomalies that may appear very much like the signal from the target of interest, but are not well-fit by a magnetic dipole model.

In this work, the performance of a tracker is compared to that of the smoother. In particular, the Rauch-Tung-Streibel and Fraser-Potter smoother was applied using the extended Kalman filter and unscented Kalman filter outputs. The performance of the filters were compared using the posterior Cramer-Rao lower bound. In addition, the tracking performance in the pre

9091-11, Session 3

An improved CPHD filter for unknown clutter backgrounds

Ronald P. Mahler, Lockheed Martin Corp. (United States); Ba-Tuong Vo, Curtin Univ. (Australia)

The “clutter-agnostic” CPHD filter was introduced at the 2010 SPIE Defense, Security & Sensing Symposium in 2010, and has been investigated in subsequent papers. In its original form, this “kappa-CPHD filter” was capable of multitarget detection and tracking in unknown, dynamically changing clutter backgrounds. It was also capable of estimating the entire intensity function of the clutter process. The purpose of this paper is to introduce a generalization of this filter. The generalized kappa-CPHD filter has the following two major improvements: (1) a formula for the probability distribution on the number of targets (target cardinality distribution); and (2) a formula for the probability distribution of the number of clutter measurements (clutter cardinality distribution). As a consequence, the entire clutter process can now be estimated (i.e., both the clutter intensity function and the clutter cardinality distribution). We also provide simulation results for the new filter.

9091-12, Session 3

CPHD filters for unknown clutter and target-birth processes

Ronald P. Mahler, Lockheed Martin Corp. (United States)

The “background-agnostic” CPHD filter was introduced at the 2010 SPIE Defense, Security & Sensing Symposium in 2010. It is a CPHD filter that is capable of operation when both the clutter background and the target-detection profile are unknown and dynamically changing. These CPHD filters are also capable of on-the-fly estimation of the intensity function and cardinality distribution of the clutter process. Leveraging ideas of Ristic, Clark, and Vo, this paper describes a generalization of the background-agnostic CPHD filter that is, in addition, capable of on-the-fly estimation of the intensity function and cardinality distribution of the target-appearance process.

9091-13, Session 3

Hybrid multi-Bernoulli CPHD filter for superpositional sensors

Santosh Nannuru, Mark Coates, McGill Univ. (Canada)

Several filters based on the random finite set framework have been recently proposed for the problem of multi-target tracking using a superpositional sensor observation model (in which the measurement effects caused by individual targets combine in an additive manner). In this setting, the multi-Bernoulli filter is able to provide more accurate target location estimates than the cardinalized probability hypothesis density (CPHD) filter, but its cardinality estimates are less robust to the arrival of new targets and the disappearance of existing targets. To address this issue, we propose in this work a hybrid between the multi-Bernoulli filter and the cardinalized probability hypothesis density (CPHD) filter. We use a multi-Bernoulli random finite set (RFS) to model the existing targets and we use an independent and identically distributed cluster (IIDC) RFS to model newborn targets and targets with low probability of existence.

Our main contributions are deriving the update equations of the hybrid filter and identifying computationally tractable approximations. We achieve this by defining conditional probability hypothesis densities (PHDs), where the conditioning is on one of the targets having a specified state. The filter performs an approximate Bayes update of the conditional PHDs. In parallel, we perform a cardinality update of the IIDC RFS component, conditioned on the estimated cardinality of the multi-Bernoulli RFS component, in order to estimate the number of newborn targets.

We provide an auxiliary particle filter based implementation of the proposed filter and compare it with PHD, CPHD and multi-Bernoulli filters in a simulated multi-target tracking application.

9091-14, Session 3

Multisensor dynamic cancellation method for spurious data based on RFS theory

Xin Chen, Ratnasingham Tharmarasa, McMaster Univ. (Canada); Anne-Laure Jousselme, Defence Research and Development Canada, Valcartier (Canada); Thiagalingam Kirubarajan, McMaster Univ. (Canada)

In this paper, the problem of cancelling spurious data using multiple information sources is studied under the framework of the random finite set (RFS) theory. It is common for real multisensor soft/hard fusion problem to have little or no prior information on the distribution of spurious data. For example, for many multisensor multitarget tracking systems, the prior information about the spurious data (i.e., clutter) is very limited. Furthermore, the distribution of spurious data of different sensors may be highly correlated, and dynamically evolve with time. Thus, in order to get a low false alarm rate, the sequences of information from different sources need to be preprocessed and the correlated spurious data will be cancelled. In this paper, a method that uses measurement sets from different sensors and inputs from several operators to dynamically cancel the spurious data, which are correlated between different information sources, are proposed. Here, it is assumed that, due to the environment background, interference, and the error of human operators, there are spurious data that are correlated between different information sources. Based on this assumption, a stochastic differential equation (SDE) driven by several jump processes is used to model the correlated spurious data. Then, the RFS theory is used to derive a dynamical cancellation method to reduce the expected number of spurious detection reports.

Finally, the spurious data cancellation preprocessor is integrated into the classic fusion algorithms. Through simulations, it is shown that the proposed spurious data cancellation method is able to improve the performance of the fusion algorithm when the distribution of spurious data is unknown.

9091-15, Session 3

Simulation-based examination of performance limits for decentralized multi-agent surveillance and tracking of undersea targets

Cameron K. Peterson, Andrew J. Newman, James C. Spall, Johns Hopkins Univ. Applied Physics Lab. (United States)

This paper examines the limits of performance for an ensemble of cooperating, mobile sensing agents executing an undersea surveillance mission. The objective of the multi-agent ensemble is to minimize uncertainty concerning the presence and location of targets as the multi-target system evolves over time. Each agent is capable of sensing, communicating with other agents, processing data to infer states of interest (fusion), and deciding on and executing motion commands. Each agent continually executes a perception-action cycle in which it fuses information to determine its best estimate of the multi-target system state and decides on its next (and possibly future) motion action(s) to optimize a criterion related to its entropic state (quantification of information gap).

Each agent's perception of the states of interest is derived from measurements captured by its own sensor(s) and information communicated by other agents. Each agent's decisions are based on its estimates of the multi-target system state, its entropic state, and its predictions of peer agent actions. The multi-agent cooperative decision making can be modeled as a cyclic optimization whereby the joint decision vector is optimized by sequentially optimizing each individual agent's decision vector while holding the others fixed. Moreover, the problem is a cyclic stochastic optimization (CSO) whereby only noisy measurements of the objective function are available to each agent. Preliminary theoretical results have recently emerged regarding convergence conditions and sub-optimality for CSO. This paper examines the implications and applicability of CSO convergence and sub-optimality via simulation-based experiments in the context of a cooperating multi-agent ensemble of undersea sensing agents searching a region for new targets and maintaining track on all discovered targets. Simulation results indicate that the theoretical results provide useful guidance on predicting the empirically observed limits of performance of the multi-agent ensemble.

9091-16, Session 3

Fusion of imaging data and auxiliary signal for target classification

Aleksandar Zatezalo, Ssu-Hsin Yu, Scientific Systems Co., Inc. (United States)

Fusion of imaging data with auxiliary signal such as EW data for multitarget classification poses daunting theoretical and practical challenges. The problem is exacerbated by issues such as asynchronous data flow, uneven feature quality and object occlusion. In our approach, we assign prior probabilities to image and signal feature elements to handle those practical issues in a unified manner. Current state and class probability distributions estimated from previous instances are fused with new outputs from individual classifiers immediate after the outputs become available to establish updated state and class probability distributions in a Bayesian framework. Results are presented that demonstrate joint segmentation and tracking, target classification using imaging data, and fusion of imaging data with noisy and asynchronous auxiliary EW information under realistic simulation scenarios.

9091-17, Session 3

Space collision threat mitigation

Aleksandar Zatezalo, Scientific Systems Co., Inc. (United States); Dusan M. Stipanovic, Univ. of Illinois at Urbana-Champaign (United States); Raman K. Mehra, Scientific Systems Co., Inc. (United States); Khanh Pham, Air Force Research Lab. (United States)

Mitigation of possible collision threats to current and future operations in space environments is an important and challenging task considering high nonlinearity of orbital dynamics and discrete measurement updates. Such discrete observations are relatively scarce with respect to space dynamics including possible unintentional or intentional rocket propulsion based maneuvers even in scenarios when measurement collections are focused to a one single target of interest. In our paper, this problem is addressed in terms of multihypothesis and multimodel estimation in conjunction with multi-agent multigoal game theoretic guaranteed evasion strategies. Collision threat estimation is formulated using conditional probabilities of time dependent hypotheses and spacecraft controls which are computed using Liapunov-like approach. Based on this formulation, time dependent functional forms of multi-objective utility functions are derived given threat collision risk levels. For demonstrating developed concepts, numerical methods are developed using nonlinear filtering methodology for updating hypothesis sets and corresponding conditional probabilities. Space platform associated sensor resources are managed using previously developed and demonstrated information-theoretic objective functions and optimization methods. Consequently, estimation and numerical methods are evaluated and demonstrated on a realistic Low Earth Orbit collision encounter.

9091-18, Session 4

Renormalization group flow and other ideas inspired by physics for nonlinear filters, Bayesian decisions, and transport

Frederick E. Daum, Jim Huang, Raytheon Co. (United States)

We derive a new particle flow for nonlinear filters inspired by Grisha Perelman's magical use of Richard Hamilton's Ricci flow to prove the Poincare conjecture. In particular, Perelman shows that Ricci flow is a gradient flow on a manifold with the Fisher information matrix used to define the action and entropy, and he shows that it is the solution of the Fokker-Planck equation, which is exactly how we compute our particle flow for nonlinear filters and for transport and Bayesian decisions. Moreover, both methods start with a homotopy. We also explain the fascinating connections with renormalization group flow and Einstein's use of Ricci curvature for gravitation. There is also a connection between Ricci flow and renormalization group flow in quantum field theory. Moreover, there is a speculative connection with proving the Riemann hypothesis using this viewpoint, suggested by Michel Lapidus. Our latest and best particle flow (method #18) also uses the observed Fisher information matrix to compute the flow. Also, our incompressible flow works in dimensions of $d = 2$ or higher, whereas in $d = 1$ it suffers from singularities which the particles cannot avoid by flowing around; this is analogous to Whitney's trick in topology, which works in higher dimensional spaces (where there is more room to maneuver) but not in low dimensional spaces, and which explains why it was much easier for Steve Smale to prove the Poincare conjecture in spaces with dimension higher than $d = 4$, whereas the proof in $d = 3$ eluded many attempts by many smart mathematicians for five decades.

We have invented a new nonlinear filter theory that is many orders of magnitude faster than standard particle filters for the same accuracy. Moreover, our filter beats the extended Kalman filter accuracy by several orders of magnitude for difficult nonlinear problems. This theory can be applied to essentially any estimation or decision problem, including: tracking, guidance and navigation, control, robotics, Bayesian decisions, predicting the weather and the stock market. We show many numerical results for various nonlinearities, with both stable and unstable plants, varying process noise, measurement noise, initial uncertainty of the state vector, and dimension of the state vector from $d = 1$ to 42. Our theory uses particle flow (like physics) to compute Bayes' rule, rather than a pointwise multiply. We do not use resampling of particles or proposal densities or importance sampling or any Markov chain Monte Carlo method. But rather, we design the particle flow with the solution of a linear first order highly underdetermined PDE, like the Gauss divergence law in electromagnetics. The talk explains what a particle filter is, and why engineers like particle filters, but we also explain the curse of dimensionality. We explain particle

degeneracy and how we solve it with a simple cartoon. This talk is for normal engineers who do not have nonlinear filters for breakfast.

9091-19, Session 4

Supersymmetry and nonlinear filtering

Bhashyam Balaji, Defence Research and Development Canada (Canada)

A fundamental consequence of relativistic quantum field theory (the spin-statistics theorem) is that the the fundamental particles are either integral spin (bosons, such as photons) or half-integral spin (or fermions, such as electrons). The quantum field theory describing the particles and their interaction observed is a specific gauge theory referred to as the standard model of strong, weak and electromagnetic interactions.

Supersymmetry originally arose in particle theory in an attempt to provide a unified description of all bosons and fermions. Apart from mathematical elegance and beauty, it also promised a resolution of some unattractive aspects of the standard model. A more lasting contribution of SUSY has been the impact on development of novel conjectures in pure mathematics. In particular, Witten and collaborators, have shown that SUSY can be used to shed light on (and provide a beautiful physical understanding of) deep mathematical results such as Morse theory, knot theory, topological invariants in four-dimensional manifolds the Atiyah-Singer index theorem, and most recently, the Langlands program in number theory.

In an attempt to understand certain aspect of SUSY (spontaneous breaking of supersymmetry), Witten initiated the study of supersymmetry in the simpler setting of quantum mechanics. Over the past three decades, supersymmetric quantum mechanics (SQM) has led to deep insight into several aspects of quantum mechanics, and is an active area of research.

A particularly interesting consequence of SUSY (in QFT as well as QM) is the extension of class of exactly solvable problems. For instance, from a superpotential, it is possible to construct a pair of rather different supersymmetric partner potentials that have related spectra. In the quantum mechanical context, it is related to the method of factorization first proposed by Schrodinger, and SQM has led to substantial advances in the field of integrable systems.

In nonlinear filtering theory (and numerous other applications such as time evolution of gene pool and the dynamical model of neural activity) one is led to consider the Fokker-Planck and Kolmogorov equations. For a certain class of Langevin equations, this is mathematically related to Euclidean quantum mechanics. Some of the vast literature in this subject (as well as supersymmetric Fokker-Planck equation) is reviewed and the relevance to nonlinear filtering is noted. In particular, it is noted that SUSY allows the exact solution of fundamental solution of a larger class of nonlinear filtering problems.

9091-20, Session 4

Bayesian inference and string theory

Bhashyam Balaji, Defence Research and Development Canada (Canada)

String theory is a vast, multi-faceted subject, that arose in an attempt to arrive at a consistent quantum theory of gravity. While quantum field theory views the fundamental objects as point particles, string theory views them to be one-dimensional objects, or strings. A simplified view of string theory is as a Feynman path integral with an action given by a two-dimensional nonlinear sigma model. An important connection exists between perturbative string theory and two-dimensional conformal quantum field theories.

In prior work by Balasubramaniam it was shown that the plausibility of a statistical model given the data can be interpreted as the partition function of a statistical mechanics problem, with the parameters of the statistical model specifying the thermodynamic ensemble, proximity of guess from the true distribution and the number of events the inverse temperature. A consequence is that the Occam's razor (i.e., a better fit to the data, but with as simple a model as possible), can be viewed as a competition between decreasing the energy and increasing the entropy of the ensemble.

In a recent provocative paper, Heckman noted some remarkable connections between Bayesian inference and string theory. In particular, the above analysis was generalized to consider a collective of agents that choose a different statistical model to fit the data, so that a broader class of inference strategies is is possible, and a different inference may be arrived at than an individual agent. A physical requirement is that such an inference be stable against perturbations. In the large N limit, the collective's plausibility of the model given the data, can be shown to be a Feynman path integral with the action given by a Euclidean non-linear sigma model with a metric provided by the information metric on the d-dimensional space of statistical parameters. Remarkably, the inference turns out to be stable and capable of adjusting its inference only for d=2. The conformal invariance in the sigma model arises from the requirement that the overall dependence on the number of agents drops out. Remarkably, Einstein's general relativity follows from the condition of stable statistical inference. String theory arises when one sums over the possible arrrangements of the agents in the collective.

In this paper, a more accessible discussion of the results are provided. The conjectured mathematical equivalence provides a novel perspective to Bayesian inference, which is discussed in greater detail. The challenges in carrying out a research program along the lines is also presented.

9091-21, Session 4

User metrics for graphical information fusion

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Graphical fusion methods are popular to describe distributed sensor applications such as target tracking and pattern recognition. Additional graphical methods include network analysis for social, communications, and sensor management. With the growth of graph methods for various data modalities, recent research is seeking to do multi-model graphical fusion. To better understand the usefulness of graph fusion approaches, we address metrics of analysis for user appreciation. In a use case study that combines graphs from text reports and target tracks to associate events and activities of interest we provide measures of performance (MOP) and measures of effectiveness (MOE) to determine usefulness of graphical fusion to a user. The first analysis includes the presentation of the separate graphs and methods for graph fusion visualization. To determine the MOE of usability, we address the metrics of timeliness, accuracy, credibility, and reliability.

9091-22, Session 4

An objective multisensor fusion metric for target detection

Jeffrey D. Clark, Stephen Sweetnich, Shane Fernandes, Air Force Institute of Technology (United States); Wesam A. Sakla, Air Force Research Lab. (United States)

Target detection from a single sensor is limited by the capabilities of that sensor; however, the combination of multiple sensors could improve the confidence of target detection. Confidence in the ability to detect, track and identify a target in a multi-sensor environment is influenced by intrinsic and extrinsic sensor qualities, i.e. target geo-location registration, and environmental conditions. Determination of the optimal number and types of sensors required to assist in specific target detection applications has largely been accomplished with empirical experimentation. Formulation of a multi-sensor effectiveness metric for sensor fusion is presented in this paper. This metric is validated with sensors of differing phenomenologies, including a ground-based VNIR/SWIR hyperspectral imager, a polarimetric infrared imager, and aerial electro-optical (EO) imagers. Leveraging one or a combination of these sensors may provide a higher confidence for a specific target detection application. A virtual 3D environment is used to model and analyze this multi-sensor target detection scenario. This metric incorporates

a Bayesian classification model combined with Dempster-Shafer decision analysis. A robust decision tool for fuzzy multimodal data is modeled and trained with empirical fused sensor detections. Multiple sensor-specific detection algorithms are compared and fused to characterize sensor detection models and likelihood functions of the models. Experiments on data collected through the Air Force Research Lab (AFRL) Minor Area Motion Imagery (MAMI) project show that this metric proves to be efficient and effective, providing a confidence of target detection based on fusion of multiple sensors.

The views expressed in this paper are those of the authors and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States Government.

9091-23, Session 5

Toward the quality evaluation of complex information systems

Ion-George Todoran, Laurent Lecornu, Télécom Bretagne (France); Ali Khenchaf, ENSTA Bretagne (France); Jean-Marc Le Caillec, Télécom Bretagne (France)

Recent technological evolutions and developments allow gathering huge amounts of data stemmed from different types of sensors, social networks, intelligence reports, distributed databases, etc. The information systems processing these heterogeneous data are composed of multiple modules. The interactions between the modules are not simple, making difficult the performance assessment of the entire information system. Unfortunately, possessing large quantities of data and being able to implement complex algorithms do not guarantee that the extracted information is of good quality.

The decision-makers need good quality information in the process of decision-making. We insist that for a decision-maker the information and its quality, viewed as a meta-information, are of great importance. A system not proposing to its user the information quality is in danger of not being correctly used or in more dramatic cases not to be used at all.

In literature, especially in organisations management and in information retrieval, are proposed different information quality evaluation methodologies. Unfortunately, any of those does not allow evaluating the information quality in complex and changing environments. In this article, we propose a new information quality evaluation methodology capable of dynamically estimating the information quality with data changes and/or with the information system's inner changes. Compared with the existing methodologies, we insist on the need to decompose the information system in its elementary modules. We do not consider the information system as a black box and we evaluate the quality after each module to finally arrive to the quality of the entire system. Our methodology is able to instantaneously update the system's output quality. For capturing the information quality evolution through the system, we introduce the notion of quality transfer function. It is equivalent to the signal processing transfer function but working on the quality level. The quality transfer function describes the influence of a processing module over the information quality. We also present two different views on the notion of information quality: a global one, characterising the entire system and a local one, for each processing module. The local information quality evaluation, at the output of each processing module, is done using the quality transfer function. Being able to locally evaluate the information quality allows propagating the quality through the system to its output. Thus, the local information quality changes, for example due as a result of a processing module evolution or as new data become available, will be directly captured in the global information quality. Thus, the global information quality estimation is realised using this quality propagating principle.

The validation of our methodology was carried out by simulating a recognition system. This system is based on multiple information extractors, viewed as classifiers. Each of these information extractors delivers partial information about the target. A fusion module gathers the information extractors' outputs and delivers the final information to the user. This simple system permits to automatically capture the influence of the information extractors' performances (by degrading or by ameliorating them) over the quality of the final information and thus, validating the proposed methodology.

9091-24, Session 5

Activity recognition from multi-INT data

Hillary Holloway, Eric K. Jones, Systems & Technology Research (United States); Jorge Tierno, Barnstorm Research Corp. (United States)

Multi-INT tools can aid intelligence analysts in discovering and distilling pertinent, relevant, and novel data from noisy or operationally irrelevant content. The Multi-INT Enhanced Exploitation and Analysis Tools (E2AT) program aims to develop new technologies and tools for multi-INT fusion to enhance analyst performance. In this paper, we discuss the Activity Instance Recognition & Tracking (AIRT) component of E2AT, which infers operationally meaningful activities by clustering time-sequenced multi-INT intelligence data associated with a special operations mission. The technology aims to help intelligence analysts in a supporting Processing, Exploitation and Dissemination (PED) cell to make sense of multiple streams of intelligence data in real time, and it assists them in generating intelligence products, including after action reports. Our technical approach is inspired by solutions to the problem of organizing digital photo libraries. Substantial research has been dedicated to developing simple, robust tools to help automate the processing of organizing such libraries, typically in terms of times, places, and activities. We apply and extend this work to the analogous task of organizing multi-INT information.

9091-25, Session 5

Detecting misinformation and knowledge conflicts in relational data

Georgiy M. Levchuk, Brian Riordan, Matthew Jackobsen, Aptima, Inc. (United States)

Information fusion is required for many mission-critical intelligence analysis tasks. Yet, information fusion solutions often fail because of noise in the processing pipeline. This noise can be the result of errors in data entry, reporting errors (e.g., from unreliable sources), ambiguous wording of the same concepts, deliberate misinformation, and or deceptive actions to mask the true hostile activities. Identifying these knowledge conflicts is an important yet unresolved task.

In this paper we describe a model for Detecting Relation, Entity, and Attribute Misinformation (DREAM). DREAM will provide the users with a powerful analysis tool that (1) finds feasible probabilistic association between entity and event mentions across different sources; (2) detect and remove conflicts in relational knowledge across different records; and (3) learn and detect normal, conflicting, and deceptive activity patterns among multiple entities reported in different data sources.

DREAM's process for misinformation detection produces probabilistic inferences at multiple levels of data processing, effectively becoming an integration of bottom-up and top-down reasoning. The main benefits of DREAM are thus that it does not make "hard" decisions about entity co-reference, knowledge conflict filtering, and complex activity pattern detection. These hard decisions often propagate large errors in the analysis process. Multi-level probabilistic reasoning of DREAM approximates an optimal joint co-reference, conflict detection, and activity detection, while able to use efficient inference algorithms developed previously for each analysis level.

DREAM consists of three technical components. First, Entity association model finds soft (probabilistic) associations between multiple mentions of the same entities and events using their local semantic and temporal information. This component will generate multiple possible co-reference links and their confidence scores. Second, Relation resolution model provides the first pass on cleaning the aggregated knowledge from the relations representing conflicting knowledge. Finally, Activity matching

model finds normal, hostile, inconsistent, and deceptive activities in the combined data. This model extends our algorithms for probabilistic multi-attributed graph matching and consistent graph pattern learning.

9091-26, Session 5

Information fusion: Telling the story (or threat narrative)

Laurie Fenstermacher, U.S. Air Force (United States)

Today's operators face a "double whammy" – the need to process increasing amounts of information, including "Twitter-INT" 1 (social information such as Facebook, You-Tube videos, blogs, Twitter), as well as the need to discern threat signatures in new security environments, including those in which the airspace is contested. To do this will require the Air Force to "fuse and leverage its vast capabilities in new ways".2 For starters, the integration of quantitative and qualitative information must be done in a way that preserves important contextual information since the goal increasingly is to identify and mitigate violence before it occurs. To do so requires a more nuanced understanding of the environment being sensed, including the human environment, ideally from the "emic" perspective; that is, from the perspective of that individual or group. This requires not only data and information that informs the understanding of how the individuals and/or groups see themselves and others (social identity) and how that identity filters information in their environment which, in turn, shapes their behaviors.3 The goal is to piece together the individual and/or collective narratives regarding threat, the threat narrative, from various sources of information: Is there a threat? If so, what is it? What is motivating the threat? What is the intent of those who pose the threat and what are their capabilities and their vulnerabilties?4 This paper will describe preliminary investigations regarding the application of prototype hybrid information fusion method based on a threat narrative framework.

Keywords: fusion, information fusion, identity, narrative, threat narrative

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9091-27, Session 5

Multisource data integration from Rafael Advanced Defense Systems, LTD

Gideon Weiss, Rafael USA, Inc. (United States); Zvi Yavin, Rafael Advanced Defense Systems Ltd. (Israel)

Reccilite ™ is an advanced digital EO/IR reconnaissance pod, designed to be mounted on any type of combat aircraft, as well as on Unmanned Air Systems. The system is operational with the IAF as well as with several international air-forces.

Reccelite enables day/night real-time reconnaissance imagery collection and data transfer via data link communications. The pod incorporates a four-axis stabilized turret with IR and visual channels in simultaneous collection, providing, Horizon to Horizon scan, Forward-Backward scan, Side Looking and vertical scan. Physical characteristics: Length 220 cm / 87", Diameter 40.6 cm / 16", Weight 200 kg / 440 lbs.

ImiLite™ is a cost effective multi-source, multi-task imagery intelligence exploitation system that receives, exploits and processes multiple imagery and data in a unified manner, for enhanced situational awareness and mission control. The system disseminates relevant intelligence reports, products and material over the network to authorized end users and clients.

ImiLite's capabilities include collection and exploitation of E/O, IR, SAR, GMTI and video data in various formats for both real-time and in-depth analysis. The system further combines non-imager GIS data layers, such as targets, threats, COMINT detection and mission status, within the system workflow to enhance the exploitation process. The system enables multi-source data integration, shortened exploitation cycle, immediate accessibility to relevant data, provides a variety of IMINT reports and products and incorporates unique image processing technology and algorithms. The system resides on mobile or stationary system configuration and requires Commercial Off-The-Shelf hardware and software.

9091-28, Session 5

Survey of techniques for crowd motion and activity recognition through video streams

Abdalla Al-Salah, Amir Shirkhodaie, Tennessee State Univ. (United States)

The usage of surveillance cameras for security has significantly increased in recent years and this increase is, at large, recognized because of rich volume of visual information that these systems can generate as well as their low cost. However, automatic surveillance in dynamic urban environments is a very challenging task. In this paper, we present a survey of recent publications related to understanding of the crowd's behavioral dynamics for the purpose crowd control and monitoring as well as for predicting spatiotemporal crowd trafficking, scatterness, and density population. This paper primarily presents a survey of applicable techniques essential for context-based crowd motion and activity recognition and analysis. Next, it presents a framework for understanding of crowd dynamic behaviors under different task constraints taxonomy and ontology; and finally it presents a summary of pertinent robust imagery processing techniques for spatiotemporal characterization and tracking of multiple targets in urban environments. The applications of techniques such as: Multi-Camera Multi-Target Tracking (MCMTT), and Crowd Motion Analysis (CMA), and Semantic Video Processing and Summarization are discussed. Generating semantic annotation of video imagery is specifically deemed crucial for comprehension of crowd dynamic interactions by human analysts. They are also considered instrumental in fusion of soft and hard sensor data/information since they may jointly reveal critical information. In this paper, we further infer the application of soft and hard sensor data/information from multi-camera surveillance systems and discuss their implication in the context of Intelligent Persistent Surveillance Systems (IPSS). Lastly, this paper identifies areas where additional researches are required to further develop and enhance this research field.

9091-29, Session 6

Group activity discovery and recognition through multilayered hidden Markov model

Vinayak Elangovan, Amir Shirkhodaie, Tennessee State Univ. (United States)

Discovery and recognition of group activities based on imagery data processing have significant applications in civilian and military domains. The process is typically involved with tedious trail analysis of video imagery with spatiotemporal implications. Discretion of video imagery requires a proper inference model capable of discriminating and differentiating cohesive observations and interlinking them to known ontologies. To address this concern, a multi-layered Hidden Markov Model (HMM) is proposed to recognize different levels of abstract group activities. The multi-layered HMM consists of N layers of HMMs where each layer comprises of M number of HMMs running in parallel. The number of layers depends on the order of information to be extracted. At each layer, by matching and correlating attributes of detected group events, the model attempts to associate sensory observations to known ontology perceptions. This paper

demonstrates and compares performance of three different implementation of HMM, namely, concatenated N-HMM, cascaded C-HMM and hybrid H-HMM for building effective multi-layered HMM. In N-HMM, every nth consecutive observation sequence is analyzed whereas in C-HMM, the inputs from the neighboring models are factored in the layered model. In H-HMM, layered models are developed for each concept group. In this approach, three main HMM layers are considered including: human-human, human-object and human-vehicle layers each of which responsible for handling respective interactions for recognition of group activities involving humans, vehicles and objects. A fusion strategy is also discussed for fusion of information gathered through each layered HMM. To demonstrate the merit of these approaches, experimental results from three different models are presented which verifies and validates the significance each multi-layered HMM for the surveillance applications.

9091-30, Session 6

Assessing the threat of firearms: New threat formula, resources, and ontological linking algorithms

Christian F. Hempelmann, Abdullah N. Arslan, Salvatore Attardo, Grady P. Blount, Nikolay M. Sirakov, Texas A&M Univ.-Commerce (United States)

The present work is part of an ongoing larger project [1, 2, 3]. The goal of this project is to develop a system capable of automatic threat assessment for instances of firearms use in public places. The main components of the system are: an ontology of firearms [1, 3]; algorithms to create the visual footprint of the firearms [1, 3], to compare visual information [1, 2, 3], to facilitate search in the ontology, and to generate the links between the conceptual and visual ontologies; as well as a formula to calculate the threat of individual firearms, firearms classes, and ammunition types in different environments.

One part of the dual-level ontology for the properties of the firearms captures key visual features used to identify their type or class in images, while the other part captures their threat-relevant conceptual properties. The visual ontology is the result of image segmentation and matching methods, while the conceptual ontology is designed using knowledge-engineering principles and populated semi-automatically from Web resources.

The focus of the present paper is two-fold. On the one hand, we will report on a substantial update of the initial threat formula, based on the increased population of the firearm ontology, including ammunition types and comparisons to actual incidents, and allowing for an overall more accurate assessment. On the other hand, the linking algorithms between the visual and conceptual ontologies are elaborated for faster transfer of information leading to an improvement in accuracy of the threat assessment.

9091-31, Session 6

Clustering and visualization of non-classified points from lidar data for helicopter navigation

Ferdinand Eisenkeil, Univ. Konstanz (Germany); Tobias Schafhitzel, Cassidian - EADS Deutschland GmbH (Germany); Uwe Kühne, EADS Deutschland GmbH (Germany); Oliver Deussen, Univ. Konstanz (Germany)

Helicopter pilots often have to deal with bad weather conditions and degraded views. Such situations may decrease the pilots' situational awareness significantly. The worst-case scenario would be a complete loss of visual reference during an off-field landing due to brownout or white out. In order to increase the pilots' situational awareness, helicopters nowadays are equipped with different sensors that are used to gather information about the terrain ahead of the helicopter. Synthetic vision systems are used to capture and classify sensor data and to visualize them on multifunctional displays or pilot's head up displays. Data points that could not be classified also have to be visualized to the pilot.

In this paper we propose a dynamic DBSCAN-based method to cluster and visualize unclassified and potentially dangerous obstacles in data sets recorded by a LIDAR sensor. The sensor delivers data sets in a short time interval, so a spatial superposition of multiple data sets is created. We use this superposition to create clusters incrementally. Knowledge about the position and size of each cluster is used to reduce the amount of data points and allow clusters to be stable within multiple time frames. This stability is a key feature to generate a smooth and un-distracting visualization of the clusters to the pilot. Only a few lines are indicating the position of threatening unclassified points, where a hazardous situation for the helicopter could happen, if it comes too close. The clustering and visualization form a part of an entire synthetic vision processing chain, where the LIDAR points are used to support the generation of a real-time synthetic view of the environment.

9091-32, Session 6

Multi-attributed tagged big data exploitation for hidden concepts discovery

Moath Obeidat, Amir Shirkhodaie, Tennessee State Univ. (United States)

Analysts who are using visualization methods for big data concept exploration increasingly expect to comprehend more distinct relationships and prominent concepts in support of their hypotheses or decisions. To expedite this knowledge discovery process, Vector Space Modeling (VSM) in conjunction with probabilistic analysis enables rapid knowledge-based relationship discovery while allowing for exploration of multi-embedded concepts than otherwise it is difficult to perceive. In this paper, we present a technique for intrinsic ontology concepts similarity matching based on VSM for exploitation and knowledge discovery from multimodality sensors metadata generated in Persistent Surveillance Systems (PSS). To reduce data dimensionality, Principal Component Analysis (PCA) and Latent Dirichlet Allocation (LDA) is applied to arrive at more abstract concepts. The proposed technique is able to reveal intrinsic concept relationships from multi-dimensional metadata structures. Experimental results demonstrate effectiveness of this approach for analytical ontological patterns exploitation. In this paper, the expediency of this technique for Visual Analytics application is demonstrated. The result indicates that the newly developed system can significantly enhance situation awareness and expedite actionable decision making.

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9091-33, Session 6

Dempster-Shafer theory and connections to Choquet's theory of capacities and information theory *(Invited Paper)*

Joseph S. J. Peri, Johns Hopkins Univ. Applied Physics Lab. (United States)

The axiomatic development of information theory, during the 1960's, led to the discovery of various composition laws. The Wiener-Shannon law is well

understood, but the Inf law holds particular interest because it creates a connection with the Dempster-Shafer theory. Proceeding along these lines, in a previous paper, I demonstrated the connection between the Dempster-Shafer theory and Information theory. In 1950, Gustave Choquet developed the theory of capacities in connection with potential theory. The basic concepts of Capacity theory arise from electrostatics, but a capacity is a generalization of the concept of measure in Analysis. It is well known that Belief and Plausibility in the Dempster-Shafer theory are Choquet capacities. The objective of this paper is to demonstrate the connections among the Dempster-Shafer theory, Information theory and Choquet's theory of capacities.

9091-61, Session Posters-Tuesday

A model-based multisensor data fusion knowledge management approach

Jeremy Straub, The Univ. of North Dakota (United States)

A variety of approaches exist for combining data from multiple sensors. When a thesis pre-exists the collection of data and the true or false condition of the thesis can be modeled, a model-based approach to data fusion from multiple sensors can be utilized. The model-based approach combines data based on its support for or refutation of elements of the model which in turn can be used to evaluate the truth or falsity of the experimental thesis. This model can (and in most cases will) have elements which require the collection of data by multiple sensor types, potentially across a wide area (necessitating the use of multiple concurrent craft to eliminate or reduce delay). Data may also be collected at a variety of resolutions and require various actuator capabilities (e.g., digging, scraping) for collection.

This paper presents a collection of inter-related algorithms for mapping various types of sensor data onto a thesis-based model and evaluating the truth or falsity of the model. Prior work has shown the efficacy of this approach for single-data type or limited data type combinations. This paper focuses on models that are designed to span larger collections of data types. It also considers scenarios where both human and autonomous collection may be used concurrently (which would be a typical scenario for battle field / hostile territory surveillance applications). The use of this approach for autonomously arriving at findings and for prioritizing data is considered. Techniques for updating the model (instead of arriving at an all-or-nothing true/false assertion) are also presented.

9091-62, Session Posters-Tuesday

A novel algorithm for long pseudo-code acquisition in spread spectrum communication system

Yusheng Fu, Univ. of Electronic Science and Technology of China (China) and Univ. of Delaware (United States); Zhongquan He, Chunhui Ren, Univ. of Electronic Science and Technology of China (China); Kenneth E. Barner, Univ. of Delaware (United States)

The fast capture of spread spectrum code is one of the key technologies of Direct Sequence Spread Spectrum (DSSS) communication. There are several traditional methods for the fast capture such as XFAST and AVERAGE. In this paper we propose a new algorithm based on the time domain samples and Binary search according the autocorrelation of the PN code. Firstly, signal's simple rate is reduced to a quarter of the chip rate with the received spread spectrum, and determined with a specific method, then the signal is divided into four parts by the local PN code and accumulated to a new sequence. Finally, the synchronous pseudo-code is captured with the correlation of the two new reference sequences. Experimental results demonstrate that the proposed algorihtm significantly improves the efficiency in the capture of long Pseudo-Code code in DSSS, compared with traditional methods.

9091-63, Session Posters-Tuesday

Single-filter application of iterative deconvolution and noise removal using simultaneous-optimization-by-simulation results

Abolfazl M. Amini, Southern Univ. and A&M College (United States); George E. Ioup, Juliette W. Ioup, Univ. of New Orleans (United States)

This paper introduces a method by which one can use the optimum iteration numbers for noise removal and deconvolution of sampled data for single filter application of always-convergent iterative deconvolution. The optimization, described in earlier work, is based on the minimization of the mean squared error, which is the square of the difference between the deconvolution result and the input. The always convergent method of Ioup is used for the simultaneous-optimization-by-simulation results. The optimization was done for two Gaussian impulse response functions, one narrow (rapidly converging) and the other wide (slowly converging). The input function used consisted of three narrow peaks selected to give some overlap after convolution with the Gaussian impulse response function. Normal distributed noise was added to the convolution of the input with the impulse response function. A range of signal-to-noise ratio is used to optimize the always convergent iterations for both of these Gaussians. The optimum numbers found are used in an equivalent window in the Fourier transform domain, although the non-negativity constraint can only be applied in the function domain. The single filter application is much more computationally efficient than the iterative approach. The results are compared to the function domain iterative results. The application of constraints can be achieved by returning to the function domain intermittently between single filter applications.

9091-64, Session Posters-Tuesday

A joint algorithm of hopping period estimation for frequency-hopping signals

Yusheng Fu, Univ. of Electronic Science and Technology of China (China) and Univ. of Delaware (United States); Li Feng, Chunhui Ren, Univ. of Electronic Science and Technology of China (China); Kenneth E. Barner, Univ. of Delaware (United States)

Parameter estimation is an important component in the field of frequency-hopping communication. In particular, the accuracy and the efficiency of the hopping-cycle estimation is significant for these applications. The traditional time-frequency method, e.g., Short Time Fourier Transform, cannot work well with high resolution of both time and frequency, according to Heisenberg's uncertainty principle. In this paper we propose a novel algorithm which is based on Short Time Fourier Transform (STFT) and Sparse Linear Regression (SLR). Firstly, the signal is preprocessed by STFT and the information of peaks is extracted by a first-order differential method. Secondly, the hopping segment data is processed with the SLR according to the dual sparsity of time-frequency of the hopping signal. Finally, combining the statistical transition moments, an accurate estimate of the jump cycle is achieved. Simulation results demonstrate that the estimation algorithm is more accurate and efficient in low SNR than the traditional STFT.

9091-65, Session Posters-Tuesday

Improved method for pulse sorting based on PRI transform

Chunhui Ren, Junqing Cao, Univ. of Electronic Science and Technology of China (China); Yusheng Fu, Univ. of Electronic Science and Technology of China (China) and Univ. of Delaware (United States); Kenneth E. Barner, Univ. of Delaware (United

States)

To solve the problem of pulse sorting in complex electromagnetic environment, we propose an improved method for pulse sorting through in-depth analysis of the PRI transform algorithm principle and the advantages and disadvantages this paper. The method is based on the traditional PRI transform algorithm, using spectral analysis of PRI transform spectrum to estimate the PRI centre value of jitter signal. Simulation results indicate that, the improved sorting method overcome the shortcomings of the traditional PRI jitter separation algorithm which cannot effectively sort jatter pulse sequence, in addition to the advantages of simple and accurate.

9091-66, Session Posters-Tuesday

Bearing and frequency estimation for nonstationary sources using cardiod sensors

Bhashyam Balaji, Defence Research and Development Canada (Canada)

A cardiod sensor consists of two matched dipoles arranged orthogonally in the horizontal plane as well as a colocated omnidirectional sensor. The directional nature of the dipoles makes it possible to estimate the bearing to a source. The bearing and frequency estimates are then input to the tracker. This is widely used in underwater acoustics applications.

Many standard solutions for target detection and bearing estimation are based on spectral analysis and batch processing. For instance, the arctangent estimator utilizes the time-averaged products of the observation data blocks to form the bearing estimate. Such techniques are adequate for high signal to noise ratio as well as stationary data collection scenarios.

The non-stationary case naturally leads one to consider a Bayesian state-space formulation of problem of estimating the nonstationary parameters. This is particularly important when considering the problem of parameter estimation of dim and highly manoeuvring targets. Furthermore, it incorporates the correlation structure of the source signal. In recent work, this has been investigated using the augmented complex extended Kalman filter. The measurement model is specified are given by the three observed waveforms, in the presence of uncorrelated, zero-mean observation noises. This work is further extended by considering non-stationary bearings as well as frequency. The results using filters, such as the extended Kalman filter and unscented Kalman filter, are compared with the results obtained using the standard estimators, such as the arctangent estimator as well as the posterior Cramer-Rao lower bound.

9091-67, Session Posters-Tuesday

THELMA: a mobile app for crowdsourcing environmental data

Kenneth Hintz, Faris Almomen, Christian Adounvo, Michael D' Amato, George Mason Univ. (United States); Christopher Hintz, Savannah State Univ. (United States)

No Abstract Available

9091-34, Session 7

The advantages of stereo vision in a face recognition system

Yufeng Zheng, Alcorn State Univ. (United States); Erik Blasch, Air Force Research Lab. (United States)

Humans can recognize a face with binocular vision, while computer solutions typically use a single image. It is known that the performance of face recognition (by a computer) can be improved using the score fusion of multimodal images and multiple algorithms. Thus, we seek stereo vision methods together with score fusion to enhance a face recognition system. We know that human binocular vision has many advantages such as stereopsis (3D vision), binocular summation, neural summation (binocular facilitation), singleness of vision including fusion of binocular images (cyclopean image), and eye dominance. In face recognition with stereo images, a 3D face is typically reconstructed from a pair of stereo images. Then 3D facial features are extracted for face recognition. In human visual processes, the binocular summation and singleness of vision are similar with fusion processes. Thus, we propose a multispectral face recognition system with stereo imaging capability, which is comprised of two 2-in-1 multispectral (visible & thermal) cameras and three recognition algorithms (circular Gaussian filter, face pattern byte, linear discriminant analysis). In this paper, we will present the fusion of stereo images (from left camera & right camera) at three different levels: images, features, and scores; and with two spectral images: visible and thermal. Image fusion techniques include average, pyramid-based, and wavelet-based; feature fusion is done with logical operations (AND, OR, XOR); and score fusion is achieved using variant classifiers (k-nearest neighbor, support vector machine, artificial neural network). The system performance is measured by accuracy rate and low false accept rates (FAR). Our experiments validate the approach with a multispectral face dataset consisting of the stereo face images of two spectral bands from 105 subjects.

9091-35, Session 7

A comparative study of DIGNET, average, complete, single hierarchical and k-means clustering algorithms in 2D face image recognition

Konstantinos-George Thanos, NCSR "Demokritos" (Greece); Stelios C. A. Thomopoulos, National Ctr. for Scientific Research Demokritos (Greece)

The study in this paper belongs to a more general research of discovering facial sub-clusters in different ethnicity face databases. These new sub-clusters along with other metadata (such as race, sex, etc.) lead to a vector for each face in the database where each vector component represents the likelihood of participation of a given face to each cluster. This vector is then used as a feature vector in a human identification and tracking system based on face and other biometrics. The first stage in this system involves a clustering method which evaluates and compares the clustering results of five different clustering algorithms (average, complete, single hierarchical algorithm, k-means and DIGNET), and selects the best strategy for each data collection. In this paper we present the comparative performance of clustering results of DIGNET and four clustering algorithms (average, complete, single hierarchical and k-means) on fabricated 2D and 3D samples, and on actual face images from various databases, using four different standard metrics. These metrics are the silhouette figure, the mean silhouette coefficient, the Hubert test ? coefficient, and the classification accuracy for each clustering result. The results showed that, in general, DIGNET gives more trustworthy results than the other algorithms when the metrics values are above a specific acceptance threshold. However when the evaluation results metrics have values lower than the acceptance threshold but not too low (too low corresponds to ambiguous results or false results), then it is necessary for the clustering results to be verified by the other algorithms.

9091-36, Session 7

Thermal-to-visible face recognition using multiple-kernel learning

Shuowen Hu, Prudhvi Gurram, Heesung Kwon, Alex L. Chan, U.S. Army Research Lab. (United States)

Recognizing faces acquired in the thermal spectrum from a gallery of visible face images is a desired capability for the military, intelligence, and

homeland security organizations, especially for nighttime surveillance. However, thermal-to-visible face recognition is a challenging problem, due to the wide modality gap between thermal and visible imaging. In this paper, we propose a thermal-to-visible face recognition approach based on multiple kernel learning (MKL) with support vector machines (SVMs). First, we subdivide the face into non-overlapping spatial regions or blocks using a method based on cooperative game theory. For comparison purposes, we also investigate uniform spatial subdivisions. Following this subdivision, histogram of oriented gradients features are extracted from each block and utilized to compute a kernel for each region. We apply sparse kernel ensemble learning (SKEL), which is a MKL-based approach that learns a set of sparse kernel weights, as well as the decision function of a one-vs-all SVM classifier for each of the subjects in the gallery. We also apply equal kernel weights (non-sparse) and obtain one-vs-all SVM models for the same subjects in the gallery. Only visible images of each subject are used for MKL training, while thermal images are used as probe images during testing. With subdivision generated by game theory, we achieved Rank-1 identification rate of 50.7% for SKEL and 93.6% for equal kernel weighting using a multimodal dataset of 65 subjects. With uniform subdivisions, we achieved a Rank-1 identification rate of 88.3% for SKEL, but 92.7% for equal kernel weighting.

9091-37, Session 7

Can the usage of human growth hormones affect facial appearance and the accuracy of face recognition systems?

Jake L. Rose, Thirimachos Bourlai, West Virginia Univ. (United States)

In law enforcement and security applications, the acquisition of face images is critical in producing key trace evidence for the successful identification of potential threats. The goal of the study is to demonstrate that steroid usage significantly affects human facial appearance and hence, the performance of commercial and academic face recognition (FR) algorithms. In this work, we evaluate the performance of state-of-the-art FR algorithms on two unique face image datasets of subjects before (gallery set) and after (probe set) steroid (or human growth hormone) usage. For the purpose of this study, our datasets of 73 subjects were created from multiple sources found on the internet, containing images of men and women before and after steroid usage. Next, we geometrically and photometrically pre-processed all images of both face datasets, and then, we applied FR techniques in order to match the pre-processed face images of our two datasets. Experimental results demonstrate that only a specific set of FR algorithms obtain the most accurate results (in terms of the rank-1 identification rate). This is because there are several factors that influence the efficiency of face matchers including (i) the time lapse between the before and after photos, (ii) the usage of different drugs (e.g. Dianabol, Winstrol, and Decabolan), (iii) the usage of different cameras to capture face images, and finally, (iv) the variability of standoff distance, illumination and other noise factors. All of the previously mentioned complications make matching these face images a very challenging problem and thus, further investigation is required.

9091-38, Session 7

Salient feature extraction from polarimetric SAR data

Bart Kahler, Frederick G. Harmon, Leidos (United States)

Although polarimetric radars are currently operational and have been used in remote sensing applications, most synthetic aperture radar (SAR) systems and algorithms designed and used to exploit the SAR data process a single polarization. In addition, the analysis techniques tend to focus on the amplitude of the scattered returns. Much of the information such as phase contained in the SAR data is not fully analyzed. Scattering from objects will differ with polarization in amplitude and phase. By exploiting the unique scattering contributions in the co-polarized (VV and HH) and cross-polarized (HV and VH) channels a more complete representation of the object is possible and the distinct nature of the scattering features can be fully revealed. The salient features derived from polarimetric data using a decomposition method such as Cameron includes amplitude, multipath odd or even bounce, scattering position relative to other scatters, and the elementary scatterer types such as dipole, dihedral, trihedral, and flat surface. These polarimetric techniques allow for the identification of non-random groups of elemental shapes and support distinguishing man-made objects from clutter. Using object decomposition techniques the authors will show the unique scattering features for a small set of ground targets extracted from polarimetric SAR data. Identification of robust salient features is the first step in developing a fully polarimetric target recognition algorithm.

9091-39, Session 7

Target recognition performance using limited salient features

Bart Kahler, Leidos (United States)

Most target recognition technology is based on pattern recognition techniques which require a template database to match candidate signatures against for a decision. To produce the templates the algorithm must be trained on hundreds of target signatures to obtain a statistical representation for the template signature for a given geometry, frequency, polarization, and other sensor parameters. If the database is fully populated so that no coverage gaps exist for the templates, significant storage space will be required and accessing a large database can take time to ensure that the proper target is selected. In this paper only a few features unique to each target are examined in an effort to ensure quick robust discrimination and to reduce ATR database sizes for on board sensor platform target identification. The author developed tools to extract a limited salient feature set consisting of target length, target width, and radar cross section for a small number of ground vehicles found in publicly available synthetic aperture radar data. A target recognition algorithm is then designed to exploit these salient features. The recognition performance indicates reasonable discrimination is achievable with a limited set of salient features for a small target library.

9091-40, Session 8

Dynamic object masking for relevant component scatterers

Bart Kahler, Leidos (United States)

Object recognition using synthetic aperture radar (SAR) chips frequently uses binary target masking to eliminate clutter and segment out the target scattering contributions. Segmentation performance should be enhanced by the use of dynamic object masking techniques to ensure that the most robust scattering features are the greatest contributors to the discrimination process. Such an approach does not discount the contribution of less persistent or weak scattering contributions, but reduces the influence to object recognition of such scatters across all target geometries. Two dynamic masking techniques are examined. The first method applies a weighting to the target mask so that scattering returns which are persistent over all geometries are weighted greater than scattering returns which are more aspect dependent. The second approach is more aggressive and weights specific target scattering returns based on aspect. For instance, if the front of the target is illuminated by the radar, those returns should be weighted greater than the weaker partially shadowed returns from the middle or back of the target. The second dynamic masking technique is an attempt to weight salient features and preserve their relative position and amplitude to one another. The author compares the results of a typical binary mask to the two dynamic masking approaches presented for a small set of publicly available SAR target chips.

9091-41, Session 8

Fusing maps with photos from mobile devices

Mark J. Carlotto, General Dynamics Advanced Information Systems (United States)

Data sources like Google Earth provide near worldwide map coverage of the Earth's surface. This is a valuable source of geo-spatial context for ATR, surveillance and other applications. In this paper we develop a real-time camera model that is capable of registering photos and video from mobile devices like smart phones and tablets with map data. The parameters of the camera model are determined from information supplied by the device's on board sensors. All computation is performed within the mobile device.

9091-42, Session 8

A numerical study of sensory-guided multiple views for improved object identification

Brigid A. Blakeslee, Univ. of Pennsylvania (United States); Edmund Zelnio, Air Force Research Lab. (United States); Daniel E. Koditschek, Univ. of Pennsylvania (United States)

We explore the potential on-line adjustment of sensory controls for improved object identification and discrimination in the context of a simulated high resolution camera system carried onboard a maneuverable robotic platform that can actively choose its observational position and pose. Our early numerical studies suggest the significant efficacy and enhanced performance achieved by even very simple feedback-driven iteration of the observer's view in contrast to identification from a fixed pose, uninformed by any active adaptation. Specifically, we contrast the discriminative performance of the same conventional classification system when informed by: a random "glance" at a vehicle; two random glances at a vehicle; or a random glance followed by a guided second look. After each glance, edge detection algorithms are used to isolate the most salient features of the image and template matching is performed through the use of the Hausdorff Distance, comparing the simulated "sensed" images with reference images of the vehicles. We present initial simulation statistics that overwhelmingly favor the third scenario. We conclude with a sketch of our near-future steps in this study that will entail: the incorporation of more sophisticated image processing and template matching algorithms; more complex discrimination tasks such as distinguishing between two similar vehicles or vehicles in motion; more realistic models of the observer's mobility including platform dynamics and eventually environmental constraints; and expanding the sensing task beyond the identification of a specified object selected from a pre-defined library of alternatives.

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9091-43, Session 8

Real-time 3D reconstruction of depth sequences using signed distance functions

Richard L. Tutwiler, John P. Morgan Jr., The Pennsylvania State Univ. (United States)

With the recent influx of inexpensive depth sensors such as the Microsoft Kinect, systems for 3D reconstruction and visual odometry utilizing depth have garnered new interest. Often these processes are highly parallel and can be realized in real-time through parallel computing architectures for the GPU. We represent fused depth maps as a Truncated Signed Distance Function (TSDF) which is a grid of voxels that contain the distance to the nearest surface. Point clouds of subsequent captures are aligned to the TSDF volume through error minimization, taking advantage of the fact that surfaces are implicitly defined where the distance is zero. We present a new method for minimizing the error based on absolute orientation that does not require linearization or a weighting function. To evaluate the proposed method we compare the number of iterations required for convergence, time per iteration, and final alignment error with existing Gauss-Newton nonlinear minimization methods. While we use the Microsoft Kinect due to its fused depth and color capabilities, the alignment only requires depth and is applicable to current active fused lidar systems with VNIR, SWIR, MWIR or LWIR sensors.

9091-44, Session 8

Group activity recognition via fusion of depth map and optical imaging techniques

Vinayak Elangovan, Amir Shirkhodaie, Tennessee State Univ. (United States)

Kinect cameras offers low-cost depth-map video streams and can be very complimentary to optical cameras employed in the surveillance systems. Unlike the standard optical cameras that have long range field-of-view, a standard Kinect camera can produce reliable depth-map video imagery data only for close-range observations limited to a few meters. The sensitivity of the Kinect camera is limited and degrades with the longer range observations. However, by combining range data from Kinect cameras with standard surveillance optical camera unique opportunities is achieved that could be used towards boosting detection and classification of certain events in the environment. In this paper, a sensor data fusion process for integration of observations from depth-map and optical cameras is demonstrated. The technique is applied for detection and recognition of group activities in two different environments: indoor and outdoor. This paper presents apt image processing techniques for generation of feature vectors from both optical and depth-map cameras and discusses a fusion scheme for combining information from two classifiers operating based on depth-map and optical imaging data. The proposed scheme is used for detection, tracking, and characterization of spatiotemporal group activities events. Lastly, we discuss the pros and cons of each sensor modality, and fusion benefit from integration of information from either sensor modalities that leads to further improvement of situational awareness in surveillance systems.

9091-45, Session 8

Acoustic events semantic detection, classification, and annotation for persistent surveillance applications

Amjad H. Alkilani, Amir Shirkhodaie, Tennessee State Univ. (United States)

The detection of acoustic events is a key technology for various arrays of surveillance applications, and acoustic sensors are one of the most promising sensing modalities, not only because of the rich amount of information they can capture from the environment, but also because they can be rapidly deployed, have low cost, and compact. The hearing ability of humans to recognize different sounds is remarkably robust and mimicking such abilities through acoustic sound processing is a real challenging. In the past, significant efforts have been devoted to detect and recognize the human and object acoustic sound signatures. However, the issue of comprehension of activity based on analysis of spatiotemporally correlated acoustic sound events has received a minimum attention and hence is not well understood. Identification of such activities (e.g., Human-Vehicle Interactions (HVI), Human-Object Interactions (HOI), and Human-Human Interactions (HHI)) can significantly improve situational awareness in Persistent Surveillance Systems. In this paper, salient sound events are preliminary identified and segmented via a sound energy tracking method. Upon this segmentation, frequency spectral pattern of each sound event is clustered using an optimal Gaussian Mixture Model (GMM) whose features are employed as feature vector for training of the system. In this method, the discrimination and classification of detected sound waves associated with different group activities, namely, HVI, HHI, and HOI, is achieved by an Adaptive Correlation Based Template Matching classifier. To interlinked

salient events representing an ontology-based hypothesis, a Hidden Markov Model (HMM) is employed to recognize spatiotemporally correlated events. Once such a connection is established, then, the system generates an annotation of perceived sound events or an activity by fusion. This paper discusses the technical aspects of this new development and presents the experimental results for several outdoor group activities monitored by an array of acoustic sensors.

9091-46, Session 9

An RFID-based luggage and passenger tracking system for airport security control applications

George E. Vastianos, Dimitris M. Kyriazanos, Vassilios I. Kountouriotis, Stelios C. A. Thomopoulos, National Ctr. for Scientific Research Demokritos (Greece)

Market analysis studies of recent years have shown a steady and significant increase in the usage of RFID technology. Key factors for this growth were the decreased costs of passive RFIDs and their improved performance compared to the other identification technologies. Besides the benefits of RFID technologies into the supply chains, warehousing, traditional inventory and asset management applications, RFID has proven itself worth exploiting on experimental, as well as on commercial level in other sectors, such as healthcare, transport and security. In security sector, airport security is one of the biggest challenges. Airports are extremely busy public places and thus prime targets for terrorism, with aircraft, passengers, crew and airport infrastructure all subject to terrorist attacks. Inside this labyrinth of security challenges, the long range detection capability of the UHF passive RFID technology can be turned into a very important tracking tool that may outperform all the limitations of the barcode tracking inside the current airport security control chain. The Integrated Systems Lab of NCSR Demokritos has developed an RFID based Luggage & Passenger tracking system within the TASS FP7-SEC-2010-241905 project. This paper describes application scenarios of the system categorized according to the structured nature of the environment (under specified rules and/or in a confined manner or not), the system architecture and presents evaluation results extracted from measurements with a group of different massive production GEN2 UHF RFID tags that are widely available in world market.

9091-47, Session 9

Wavelet-based identification of objects from a distance

Ershad Sharifahmadian, Yoonsuk Choi, Shahram Latifi, Univ. of Nevada, Las Vegas (United States)

In remote sensing, accurate identification of concealed far objects is difficult. Here, to detect concealed objects from a distance, wideband (WB) technology is utilized. As the WB data includes a broad range of frequencies, it can reveal information about both the surface of the object and its content.

First, WB antenna radiates tuned WB signals toward a concealed object, and reflected signals from the target in the scene are collected by receiver antenna. To improve the identification accuracy and to provide more information about the target, the collected WB data is processed in the wavelet domain.

Using wavelet transform, the collected wideband signals are simultaneously analyzed in both time and frequency domains. As the radiated and received frequencies, time, and reflected power are the only available parameters to identify the target, time-frequency analysis of the collected wideband data are crucial. In fact, information about target is spread over different wavelet subbands. More precisely, higher frequency wavelet subbands include information about exterior layers of both the target object and the background, and lower frequency wavelet subbands provide information about inner layers of the object. Therefore, it is possible to better discriminate among objects for which their frequency information is placed in the same frequency range.

The experiment is performed using WB technology at different frequency ranges (250MHz-2.2GHz) and different powers to identify a target. In conclusion, using time-frequency analysis of collected wideband data (i.e. analysis in wavelet domain), the overall accuracy to identify the unknown object can be improved.

9091-48, Session 9

rScene: A revolutionary low-cost microradar for target classification and tracking

Thomas Plummer, Richard D. Porter, Robert Raines, McQ, Inc. (United States)

A small form factor, low cost, radar named rScene® has been designed by McQ Inc. for the unattended detection, classification, tracking, and speed estimation of people and vehicles. This paper will present recent performance results relative to detection range and false alarms. Additionally, an extra-low power (<1W) processing scheme is described that allows the rScene® to be deployed for longer duration, while still detecting all desired target scenarios. Using the rScene® to detect other targets of interest like boats over water will also be addressed. Lastly, the lack of performance degradation due to hiding the rScene® in various types of concealed scenarios like behind walls, doors, foliage and camouflage material will be illustrated. rScene® provides a wide variety of options to integrate the device into both wired and wireless communication infrastructures. Based on its sophisticated signal processing algorithms to classify targets and reject clutter, it allows for operation in challenging urban environments in which traditional unattended ground sensor modalities are less effective.

9091-49, Session 9

Optimal fusion of detectors through joint posterior ratio estimation

Brandon Smock, Joseph Wilson, Taylor Glenn, Univ. of Florida (United States)

In this paper, we consider the problem of the optimal discrimination of targets using multiple detectors simultaneously. A detector is considered to be proper, meaning it optimally uses the information available to it, when its ROC curve is strictly convex. This is equivalent to saying its decision statistic, or confidence, is monotonically related to the likelihood ratio. While the use of a decision statistic that is merely monotonically related to the likelihood ratio is sufficient in the case of an isolated detector, optimally comparing the outputs of multiple detectors run simultaneously requires the estimation of a posterior ratio. However, a problem arises when multiple detectors detect the same object and assign different posterior probabilities. To remedy this, we consider each element of the power set of detectors to be an individual detector, and estimate that set's joint posterior ratio. Thus each object has a unique posterior probability assigned to it, each individual detector is proper, and their combination yields a convex ROC curve, which is optimal.

9091-50, Session 9

Distributed detection by generalized receiver in macrodiversity cellular communication systems

Vyacheslav P. Tuzlukov, Kyungpook National Univ. (Korea, Republic of)

In this paper, we consider the design of soft decision distributed detection schemes for achieving macrodiversity in uplink cellular communication systems employing the generalized receiver (GR) with and without channel knowledge at the fusion center. Distributed detection macrodiversity

techniques are proposed where the quantizer thresholds of local GR at base stations (radio access points) are optimized using a numerical global optimization algorithm called adaptive simulated annealing. The performance of such distributed detection macrodiversity GR schemes is studied for cellular systems with and without channel coding, where the base stations employ multiple receive antennas over quasi-static Rayleigh fading channels. It is shown that properly designed quantizers for the local GR, with a few resolution bits can make the detection performance very close to optimal macrodiversity that requires a much larger bandwidth from the connection links to the fusion center.

9091-51, Session 10

Fast methods for fusing visible/IR images with natural color appearance under different typical scenes

Lingxue Wang, Wei Zhang, Zhen Jin, Yuan Luo, Yi Cai, Beijing Institute of Technology (China)

Color transfer is an effective way to render black and white visible and infrared images (called source images) with natural color appearance according to the brightness and color distribution of a day-time color visible image (called reference image). The rendered results rely heavily on the reference image. But till now, no quantified method has been proposed to select a most optimal reference image for source images with different contents. At the same time, researchers have developed various methods to accurately transfer color from the reference image to the source images, such as local transfer based on image segmentation, non-linear transfer based on hot target enhancement. However, we are aiming at simplifying the complicated computation. Firstly, a large amount of reference images are categorized as several typical scenes: sea-sky scene, land-plant scene, desert-sky scene, and snow-sky scene. Secondly, fast computation algorithms are developed to obtain robust color appearances rather than very accurately transferred colors between the source image and the reference image. In this paper, fast methods for fusing and colorizing visible/IR images with natural color appearance under different typical scenes are mainly presented. Subjective observing experiments are conducted to determine that rendering hot targets in IR image light orange under land-plant scene and white under sea-sky scene will obtain good thermal contrast. Three channels of YUV color space have been modulated by the grey value of hot targets. In addition, this method is modified to colorize single band IR image and still obtain good color appearance.

9091-52, Session 10

Vision-based target detection in marine search and rescue

Shining Wang, Xiujuan Yu, China Water Transport Research Institute (China)

With today's wide applications of optical sensor in aerial aircrafts, the direct vision-based object detections from optical images are relatively adequate and popular. However, in marine search and rescue, the object detection is known as one challenging problem due to the surface fluctuations and the illumination changes on sea. In this paper, we propose a vision-based target detection scheme based on video saliency to find the rescue targets automatically.

The proposed method aims to carry out the prompt search of potential rescue object from aerial images. The main advantage of our method lies in the analysis of video features to assign saliency for different regions. Hence, a new definition of video saliency is first proposed to comprehend the target properties based on structure similarity among adjacent video frames. Then, a cascaded target detection is devised with the local image feature and regional video saliency. Considering the primary goal of target detection in marine search is to capture all potential information and decrease the false negatives, we treat the salient objects in aerial images as a basic feature to explore general search candidates in the beginning. To further pick out the accurate regions occupied by required rescue objects, we filter the false candidates based on the region-based video saliency.

The proposed method achieves robust performances in three aspects: high detection accuracy, good true detections, and low false detections. We believe that the propose method can improve the search and rescue of targets, and reduce the economical losses in marine accidents.

9091-68, Session 10

Invariant-feature-based adaptive automatic target recognition in obscured 3D point clouds

Timothy S. Khuon, Charles M. Kershner, Arnel Alverio, Enrico Mattei, National Geospatial-Intelligence Agency (United States)

Target recognition and classification in a 3D point cloud is a non-trivial process due to the nature of the data collected from a sensor system where the signal can be corrupted by noise from the environment, electronic system, A/D converter, etc... Therefore, an adaptive system with a desired tolerance is required to perform classification and recognition optimally. The feature-based pattern recognition algorithm described below, is generalized for solving a particular global problem with minimal change. Since for the given class set, a feature set must be extracted accordingly. For instance, man-made target classification and human organ classification would require different feature sets.

9091-53, Session 11

An improved ground vehicle tracking algorithm by integrating Bayesian tracking framework with an auxiliary particle filter *(Invited Paper)*

Miao Yu, Cunjia Liu, Wenhua Chen, Jonathon Chambers, Loughborough Univ. (United Kingdom)

This paper addresses the problem of ground vehicle tracking with Ground Moving Target Indicator (GMTI) radar by the aid of domain knowledge. In the ground vehicle tracking scenario, a vehicle may perform different kinds of manoeuvres (e.g. acceleration, constant velocity, or stop) during the tracking, however the movement of the vehicle is also constrained by road and its operational environment. A number of multiple state models and Monte-Carlo sampling based ground vehicle tracking algorithms have been proposed such as interacting multiple model particle filters (IMMPF) and bootstrap multiple model particle filters (BS-MMPF). In these algorithms, multiple state models are used to represent the different modes of ground vehicle movement. Monte-Carlo sampling based algorithms are able to incorporate non-linearity in both the state and measurement models in the GMTI radar based ground vehicle tracking and exploit domain knowledge such as road and terrain information. This paper presents an improved ground vehicle tracking algorithm by incorporating the more efficient auxiliary particle filter (APF) into a Bayesian tracking framework. It follows an exact Bayesian derivation of the posterior probabilities on observations and the auxiliary particle filter is able to incorporate the latest measurements into the particle updating procedure to reduce outliers. Simulations are presented to show the advantages of the improved algorithm over the existing ones. It is also shown that incorporating road information and other domain knowledge into tracking could significantly improve tracking performance.

9091-54, Session 11

Fall risks assessment among community dwelling elderly using wearable wireless sensors *(Invited Paper)*

Thurmon E. Lockhart, Rahul Soangra, Virginia Polytechnic Institute and State Univ. (United States)

Although modern medicine and new medical technologies offer enormous potential to improve diagnosis and treatment of many diseases, mortalities from fall accidents are steadily on the rise for the elderly. In this study, we evaluated community dwelling elderly individuals' postural stability utilizing a wireless inertial sensor to unobtrusively assess fall risks that maybe amendable to predicting fallers and non-fallers. In all a total of 100 community dwelling elderly individuals (66 non-fallers and 34 fallers) participated in the experiment. All participants were asked to stand-still with eyes open (EO) and eyes closed (EC) for 60 seconds each on forceplate with one wireless inertial sensor affixed at sternum level. Several linear and nonlinear postural stability parameters were extracted from this data. It is seen that some linear measures of center of pressure (COP) such as mean radius, circular area and elliptical area of COP excursion are significantly different for fallers and non-fallers ($p<0.05$). It was also found that inertial sensors could distinct faller and non-faller participants through non- linear measures of medio-lateral sway such as sample entropy. These results indicated several key variables of postural characteristics that are relevant for fall risk assessment using an inertial sensor. This study opens new prospects of simple clinical testing using a portable wireless inertial sensor by measuring postural variables that may be relevant for assessing older adults' fall risks at home and clinical environment.

9091-55, Session 11

A cyber-physical system for senior collapse detection *(Invited Paper)*

Lynne L. Grewe, Steven Magana-Zook, California State Univ., East Bay (United States)

Senior Collapse Detection (SCD) is a system that uses cyber-physical techniques to create a "smart home" system to predict and detect the falling of senior/geriatric participants in home environments. This software application addresses the needs of millions of senior citizens who live at home by themselves and can find themselves in situations where they have fallen and need assistance. We discuss how SCD uses imagery and depth to fuse and interact in a system that will not require the senior to wear any devices allowing them to be more autonomous. The Microsoft Kinect Sensor is used to collect imagery, depth and audio input. We will begin by discussing the physical attributes of the "collapse detection problem". Next, we will discuss the task of feature extraction resulting in skeleton and joint tracking. Improvements in error detection of joint tracking will be highlighted. Next, we discuss the main module of "fall detection" using our mid-level skeleton features. Attributes including acceleration, position and room environment factor into the SCD fall detection decision. Finally, how a detected fall and the resultant emergency response are handled will be presented. Results in a home environment will be given. The U.S. is entering a time in history when the number of seniors is far larger than before with the now retiring "Baby Boomers". These individuals are looking to stay in their own home environment often living alone for longer times and this system could be on solution to the ensuing problems of senior collapse.

9091-56, Session 11

Biobotic insect swarm-based sensor networks for search and rescue *(Invited Paper)*

Alper Bozkurt, Edgar Lobaton, Mihail Sichitiu, North Carolina State Univ. (United States); Tyson Hedrick, The Univ. of North Carolina at Chapel Hill (United States); Tahmid Latif, Ali Dirafzoon, Eric Whitmire, Alexander Verderber, North Carolina State Univ. (United States); Juan Marin, Middle Creek High School (United States)

The potential benefits of distributed robotics systems in applications requiring situational awareness, such as search-and-rescue in emergency situations, are indisputable. The efficiency of such systems requires robotic agents capable of coping with uncertain and dynamic environmental conditions. For example, after an earthquake, a tremendous effort is spent for days to reach to surviving victims where robotic swarms or other distributed robotic systems might play a great role to achieve this faster. However, current technology falls short in offering centimeter scale mobile agents that can function effectively under such conditions. Insects, the inspiration of many robotic swarms, exhibit an unmatched ability to navigate through such environments while successfully maintaining control and stability. We have benefitted from recent developments in neural engineering and neuromuscular stimulation research to fuse the locomotory advantages of insects with the latest developments in wireless networking technologies to enable biobotic insect agents to function as search-and-rescue agents. Our research efforts towards this goal include development of biobot electronic backpack technologies, establishment of biobot tracking testbeds to evaluate locomotion control efficiency, investigation of biobotic control strategies with Gromphadorhina portentosa cockroaches and Manduca sexta moths, establishment of a localization and communication infrastructure, modeling and controlling collective motion by learning deterministic and stochastic motion models, topological motion modeling based on these models, and the development of a swarm robotic platform to be used as a testbed for our algorithms.

9091-57, Session 11

A social-based cyber-physical system for distributed message transmission *(Invited Paper)*

Haiying Shen, Kang Chen, Clemson Univ. (United States)

The explosive increase of the availability of personal mobile devices has brought about a significant amount of peer-to-peer communication opportunities upon their encountering, which can be exploited to realize distributed message transmission among mobile devices. However, the opportunistic encountering among mobile devices, which is determined by the mobility of their holders, has introduced great difficulties on efficiently transmitting a message to its designated destination. Actually, people usually present a certain pattern on daily mobility. Further, device holders often belong to a certain social network community. Therefore, in this paper, we propose a social-based cyber-physical system for distributed message transmission, namely SocMessaging, by integrating both the mobility pattern and the social network of device holders. When selecting an encountered node for message relay, in addition to the node's historical encountering records with the destination node, SocMessaging also considers its social closeness with the destination node. Then, the message is always transmitted to the node that is most likely to meet its destination. As a result, SocMessaging closely connects the cyber world (i.e., network), physical world (i.e., people) and social network (i.e., social connection). Finally, our experimental results demonstrate the efficiency of the proposed system in message transmission between device holders.

9091-58, Session 11

TrustQ: A category reputation based Q&A system *(Invited Paper)*

Yuhua Lin, Haiying Shen, Clemson Univ. (United States)

Question and Answering (Q&A) systems aggregate the collected intelligence of all users to provide satisfying answers for questions from users. A well-developed Q&A system should provide high question response rate, low response delay and good answer quality. Previous works use reputation systems to achieve the goals. However, these reputation systems evaluate a

user with an overall rating for all questions the user has answered regardless of the question categories, thus the reputation score cannot accurately reflect the user's ability to answer a question in a specific category. In this paper, we propose TrustQ, a category reputation based Q&A System. TrustQ evaluates the reputations of users' willingness and capability to answer questions in different categories. Considering a user has different willingness to answer questions from different users, TrustQ lets each node evaluate the reputation of other nodes answering its own questions. User a calculates user b's final reputation by considering both user a's direct rating and the indirect ratings on user b from other nodes. The reputation values facilitate forwarding a question to potential answerers, which improves the question response rate, response delay and answer quality. Our trace-driven simulation on PeerSim demonstrates the effectiveness of TrustQ in providing good user experience in terms of response rate and latency, and the answer quality.

9091-59, Session 11

High-assurance SPIRAL *(Invited Paper)*

Franz Franchetti, Carnegie Mellon Univ. (United States)

In this paper we introduce "High Assurance SPIRAL" to solve the "last mile" problem for the synthesis of high assurance implementations of controllers for vehicular systems that are executed in todays and future embedded and high performance embedded system processors. High Assurance SPIRAL is a scalable methodology to translate a high level specification of a high assurance controller into a highly resource-efficient, platform-adapted, verified control software implementation for a given platform in a language like C or C++. High Assurance SPIRAL proves that the implementation is equivalent to the specification written in the control engineer's domain language. Our approach scales to problems involving floating-point calculations and provides highly optimized synthesized code. It is possible to estimate the available headroom to enable assurance/performance trade-offs under real-time constraints, and enables the synthesis of multiple implementation variants to make attacks harder. At the core of High Assurance SPIRAL is the Hybrid Control Operator Language (HCOL) that leverages advanced mathematical constructs expressing the controller specification to provide high quality translation capabilities. Combined with a verified/certified compiler, High Assurance SPIRAL provides a comprehensive complete solution to the efficient synthesis of verifiable high assurance controllers. We demonstrate High Assurance SPIRAL's capability by co-synthesizing proofs and implementations for attack detection and sensor spoofing algorithms and deploy the code as ROS nodes on the Landshark unmanned ground vehicle and on a "Synthetic Car" in a real-time simulator.

9091-60, Session 11

Deceiving entropy-based DoS detection *(Invited Paper)*

Ilker Ozcelik, Richard R. Brooks, Clemson Univ. (United States)

Denial of Service (DoS) attacks disable network services for legitimate users. Although World Wide Web (WWW) is the first thing comes into mind when discussing about DoS, networks used for critical infrastructures; such as smart grid and public utilities; suffer from these attacks. A McAfee report shows that eight out of ten Critical Infrastructure Providers (CIPs) surveyed had faced a significant Distributed DoS (DDoS) attack in 2010. Researchers have proposed many approaches for detecting these attacks in the past decade. Anomaly based DoS detection is the most common approach. In this approach, the detector uses network traffic statistical features; such as the entropy of incoming packet header fields like source IP addresses or protocol type. It continuously calculates the observed statistical feature and triggers an alarm if an extreme deviation occurs. However, intrusion detection systems (IDS) using entropy based detection approaches can be a victim of spoofing attacks. An attacker can sniff the network and calculate background traffic entropy value of the observed feature before a (D)DoS attack starts. Then he can spoof attack packets to keep the entropy value in the expected range during the attack. In this study, we discuss how we can deceive entropy based detection approaches. We present a proof of concept entropy spoofing attack. Our preliminary results show that our spoofing attack can deceive entropy based DoS attack detection approaches and cause a significant detection performance degradation.

Conference 9092: Signal and Data Processing of Small Targets 2014

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9092-1, Session 1

Application of rich feature descriptors to small target detection in wide-area persistent ISR systems

Christopher W. Miller, Jason A. Edelberg, Michael L. Wilson, U.S. Naval Research Lab. (United States)

One of the desired capabilities for wide-area persistent ISR systems is to reliably track the movement of targets within the associated large camera field of view. Current wide-area persistent ISR systems are characterized by very large pixel count images (often exceeding 100 Mpixels/frame) but, due to the associated large ground area covered, still provide relatively few pixels associated with the desired target classes (typically vehicles and/or dismounts). Large overall pixel counts lead to large computational burdens on all image processing tasks yet there remains a strong desire to use image structure to assist in the association of small targets among successive frames. Both of these factors make detection and tracking of targets difficult. Most object-recognition and object-classification techniques rely on a large number of pixels on target and a large set of training data. Neither of these necessary inputs are typically available in wide-area persistent ISR applications. To address this need, we have applied several rich image feature descriptors to sample wide-area persistent ISR image series. Despite the limited numbers of pixels on target available, we will demonstrate robust feature-based object-detection. These results will also be compared to those resulting from a conventional change-based target detection/association algorithm. Finally, we will discuss the computational costs associated with these techniques and mechanisms for management of computational load against the large image sizes needed.

9092-2, Session 1

Detection of small targets and their characterization based on their formation using an image feature network-based object recognition algorithm

Jeremy Straub, The Univ. of North Dakota (United States)

Small target detection and classification (particularly in the case of point targets) is problematic. Characteristics other than visual image-based identification (i.e., metadata) can be utilized in an attempt to make a classification decision; however, this may not always be available (or even collectable) or its collection may impair classification decisions in a time-critical environment. In some cases, these small targets operate as part of a cluster, where classification can be performed based on the characteristics of the cluster's operations, instead of trying to identify an individual cluster-member directly. Cluster-based identification, however, relies on formation identification and/or movement analysis. These characteristics can be arbitrarily manipulated (particularly prior to and after task performance) by an adversary attempting to obfuscate their intent.

This paper presents an algorithm for object identification based on comparing networks of point-to-point distances between features identified by an image feature detection algorithm. This algorithm is both scale and orientation agnostic. Once the network has been normalized, it is then compared to other networks of known objects to (prospectively) make a classification assertion (if one is a strong enough match). Once the basic version of the algorithm has been presented, the paper discusses the alterations required to make the algorithm suitable for performing cluster-formation based characterization of small targets from point or near-point source data. The advantages and drawbacks of this approach are discussed. The possibility of both inadvertent and intentionally-created false positives and false negative matches is discussed. The possibility of miss-identification is also considered and discussed. An analysis of the algorithm's performance is presented and it efficacy for this application assessed.

9092-3, Session 1

Advancement and results in hostile fire indication using potassium-line missile warning sensors

Joel B. Montgomery, Marjorie Montgomery, M&M Aviation (United States)

M&M Aviation has been developing and conducting Hostile Fire Indication (HFI) tests using potassium line emission sensors for the Air Force Visible Missile Warning System (VMWS) to advance both algorithm and sensor technologies for UAV and other airborne systems for self protection and intelligence purposes. Work began in 2008 as an outgrowth of detecting and classifying false alarm sources for the VMWS using the same K-line spectral discrimination region but soon became a focus of research due to the high interest in both machine-gun fire and sniper geo-location via airborne systems. Several initial tests were accomplished in 2009 using small and medium caliber weapons including rifles. Based on these results, the Air Force Research Laboratory (AFRL) funded the Falcon Sentinel program in 2010 to provide for additional development of both the sensor concept, algorithm suite changes and verification of basic phenomenology including variance based on ammunition type for given weapons platform. Results from testing over the past 3 years have showed that the system would be able to detect and declare a sniper rifle at upwards of 3km, medium machine gun at 5km, and explosive events like hand-grenades at greater than 5km. This paper will outline the development of the sensor systems, algorithms used for detection and classification, and test results from VMWS prototypes as well as outline algorithms used for the VMWS. It will also cover basic signal to noise ratios and spatial-spectral-temporal features used for extraction purposes with a comparison against larger artillery pieces done for space-based detection and location. Finally, the paper will show the future work for ATD and transition efforts after the Falcon Sentinel program completed.

9092-4, Session 1

Plot enchaining algorithm: A novel approach for clustering flocks of birds

Gulay Buyukaksoy Kaplan, Adnan Lana, TUBITAK UME (Turkey)

Migrating birds in airport vicinity are a potential risk of serious hazard. To reduce the risk, flocks of birds should be detected and identified in the radar measurements before they reach the aircraft route and become dangerous. For group of targets such as flock of birds, there is no need to track each target individually. Instead a cluster can be used to represent closely spaced tracks of a possible group. Considering a group of targets as a single target for tracking provides significant performance improvement with almost no loss of information.

In this study, we proposed a novel clustering approach specialized for grouping radar plots which are assumed to be originating from flocks of birds and is named as Plot Enchaining (PE) algorithm due to the way it works. To evaluate its performance, the results are compared to the results of well-known Simple Cluster-Seeking (SCS) algorithm for real radar observations.

PE algorithm uses distance between plot borders in radar video signal, instead of distance between centers of the plots as in most of the clustering algorithms. The other distinctive feature of the algorithm is to make use of the distance between migrating birds.

Input data for comparing the algorithms were acquired in TUBITAK Gebze campus with horizontal scanning pulse radar (FURUNO) during autumn migration of storks. Recorded data has a length of 500 scans with a period

of 2.7 seconds.

The proposed PE algorithm outperform SCS algorithm in terms of associating closely spaced plots. Every plot association decision of SCS algorithm is also made by PE. Additional associations of PE algorithm result in more comprehensive and meaningful grouping.

9092-5, Session 1

Polar synthetic aperture radar imaging based on Maxwell's equations

Zhijun G. Qiao, The Univ. of Texas-Pan American (United States); Bing Sun, BeiHang Univ. (China) and The Univ. of Texas-Pan American (United States); Jacob Banda, The Univ. of Texas-Pan American (United States)

A general synthetic aperture radar (SAR) signal model based on the Maxwell's equations is derived, and three approximations are discussed for engineering applications. Based on this signal model, a novel operation of SAR, called polar synthetic aperture radar, is investigated for wide observation. The polar SAR works similarly to the general circular SAR, but the beam of the SAR antenna points at the outer of the circle instead of the inner. The signal model and imaging algorithm are presented for the polar SAR, and furthermore, simulation is given to validate the signal model and imaging algorithm.

9092-6, Session 1

Multiset singular-value decomposition for image fusion

Darren K. Emge, U.S. Army Edgewood Chemical Biological Ctr. (United States)

In forensic analysis the increased use of multiple illumination sources is producing a need to merge those images to more accurately delineate targets of interest. The multi-set singular value decomposition (MSVD) offers a solution to this complex problem. The MSVD extends the generalized singular value decomposition (GSVD) method from two data matrices, or images, to N data matrices. This is accomplished by projecting the data from all modalities into a pseudo dispersion space, defined as the arithmetic mean of all pair-wise inter spatial projections. This pseudo dispersion can be shown to share the eigen-values with all single mode SVDs and the eigen-decomposition of this pseudo dispersion space can be used to determine the common right side basis vectors. The resulting eigen-values can be used to determine a common order for all modalities and reduce the combine data set to reveal common targets. The MSVD method will be demonstrated using a simulated target inserted into a set of standard images. The simulated data will show the properties of the projections achieved using the MSVD factorization and to explore their characteristics. Additionally the MSVD method will be applied to fingerprint imagery utilizing multiple illuminations sources. This application will show the applicability of the MSVD method to improve the processing of forensic data.

9092-7, Session 1

Non-blind beamforming and DOA estimation by generalized receiver in MIMO wireless communication systems

Vyacheslav P. Tuzlukov, Jin Gui Liu, Modar S. Shbat, Kyungpook National Univ. (Korea, Republic of)

In this paper, we investigate the generalized receiver (GR) constructed based on the generalized approach to signal processing in noise employing non-blind beamforming algorithms and direction of arrival (DOA) estimation, which is implemented by MIMO wireless communication systems. Three non-blind beamforming algorithms, namely, the least mean square (LMS), the recursive least square (RLS), and the sample matrix inverse (SMI) are compared under employment by GR. DOA techniques are applied based on multiple signal classification (MUSIC) and estimation of signal parameters via rotational invariance technique (ESPRIT). We suppose several GR structures employing the above mentioned non-blind beamforming algorithms jointly with DOA estimation. Comparative analysis of simulation results allows us to make a conclusion that the performance curves of GR with considered non-blind beamforming algorithms are very close to each other. Also, simulation results demonstrate superiority in the output signal-to-interference-plus-noise ratio (SINR) under employment of GR with the discussed non-blind beamforming algorithms and DOA estimation in MIMO wireless communication systems in comparison with the Neyman-Pearson detector.

9092-8, Session 2

Particle filter for very long-range radar with high-range accuracy

Kevin Romeo, Peter K. Willett, Yaakov Bar-Shalom, Univ. of Connecticut (United States)

In this paper we present an approach for tracking with a high-bandwidth active radar in very long range scenarios with 3-D measurements in r-u-v coordinates. The 3-D low-process-noise scenarios considered are much more difficult than the ones we have previously investigated where measurements were in polar coordinates. We show that in these 3-D scenarios the extended Kalman filter and its variants are not desirable as they suffer from either major consistency problems or degraded range accuracy, and most flavors of particle filters suffer from a loss of diversity among particles after resampling. This leads to sample impoverishment and divergence of the filter. In the scenarios studied, this loss of diversity can be attributed to the very low process noise. However, a regularized particle filter is shown to avoid this diversity problem while producing consistent results. The regularization is accomplished using a modified version of the Epanechnikov kernel.

9092-9, Session 2

Tracking targets with low signal-to-noise ratio using particle filtering with flow control

Nima Moshtagh, Paul M. Romberg, Steve G. Spray, Moses W. Chan, Lockheed Martin Space Systems Co. (United States)

In this work we study the problem of detecting and tracking challenging targets that exhibit a signal-to-noise ratio (SNR) of less than one. Traditional approaches to improving SNR involve signal processing methods such as image co-addition, which increases SNR by a factor of the square root of number of images used. The main problem with this approach is that its performance degrades drastically for moving targets. We have developed a recursive Bayesian track-before-detect (TBD) algorithm, implemented using a particle filtering technique. This approach incorporates the latest state estimate to control the particle flow accounting for target dynamics. The flow control enables accumulation of signal information over time to compensate for target motion. The performance of this approach is evaluated using a sensitivity analysis based on varying target speed and SNR. This analysis was conducted using high-fidelity sensor and target modeling in realistic scenarios. Our results show that this TBD algorithm is capable of tracking targets in cluttered images with SNR values much less than one.

9092-10, Session 2

How to avoid normalization of particle flow for nonlinear filters, Bayesian decisions and transport

Frederick E. Daum, Jim Huang, Raytheon Co. (United States)

We derive a new particle flow for nonlinear filters inspired by renormalization group flow (RGF) in quantum field theory. The interesting connection between our particle flow and renormalization group flow (RGF) in quantum field theory (QFT), was suggested by Bashyam Balaji. In particular, according to Professor Tony Zee RGF is "the most important conceptual advance in quantum field theory over the last three or four decades". RGF is for a set of particles in d-dimensional space with an artificial parameter, μ, that is suspiciously like our homotopy parameter, and furthermore, one could consider RGF as "the trick of doing an integral a little bit at a time" which sounds like the basic idea of our log-homotopy. Moreover, there is a connection between RGF and RIcci flow in physics and topology.

We have invented a new nonlinear filter theory that is many orders of magnitude faster than standard particle filters for the same accuracy. Moreover, our filter beats the extended Kalman filter accuracy by several orders of magnitude for difficult nonlinear problems. This theory can be applied to essentially any estimation or decision problem, including: tracking, guidance and navigation, control, robotics, Bayesian decisions, predicting the weather and the stock market. We show many numerical results for various nonlinearities, with both stable and unstable plants, varying process noise, measurement noise, initial uncertainty of the state vector, and dimension of the state vector from d = 1 to 42. Our theory uses particle flow (like physics) to compute Bayes' rule, rather than a pointwise multiply. We do not use resampling of particles or proposal densities or importance sampling or any Markov chain Monte Carlo method. But rather, we design the particle flow with the solution of a linear first order highly underdetermined PDE, like the Gauss divergence law in electromagnetics. The talk explains what a particle filter is, and why engineers like particle filters, but we also explain the curse of dimensionality. We explain particle degeneracy and how we solve it with a simple cartoon. This talk is for normal engineers who do not have nonlinear filters for breakfast.

9092-11, Session 2

Seven dubious methods to mitigate stiffness in particle flow with non-zero diffusion for nonlinear filters, Bayesian decisions and transport

Frederick E. Daum, Jim Huang, Raytheon Co. (United States)

We derive a new particle flow for nonlinear filters using the Yang-Mills equations. Our PDE for particle flow is the d-dimensional version of the Gauss divergence law, which is the first of Maxwell's equations. Yang-Mills is a nonlinear generalization of Maxwell's equations. Moreover, gauge transformations are standard in exact fixed finite dimensional nonlinear filter theory (Mitter 1979). The nonlinear PDE for exact fixed finite dimensional filters in the exponential family derived by Daum (1986) is roughly analogous to the Yang-Mills equations. We also explain the connection with renormalization group flow, which is what makes Yang-Mills work for quantum field theory. These interesting connections were inspired by discussions with Bashyam Balaji about nonlinear filters and quantum field theory. One can derive all of Maxwell's equations from the Gauss divergence law and Lorentz invariance; we find it extremely interesting that we had to impose a speed limit on particles for our Coulomb's law flow, analogous to the limit on the speed of light that is evident in the real world, which corresponds to Lorentz invariance.

We have invented a new nonlinear filter theory that is many orders of magnitude faster than standard particle filters for the same accuracy. Moreover, our filter beats the extended Kalman filter accuracy by several orders of magnitude for difficult nonlinear problems. This theory can be applied to essentially any estimation or decision problem, including: tracking, guidance and navigation, control, robotics, Bayesian decisions, predicting the weather and the stock market. We show many numerical results for various nonlinearities, with both stable and unstable plants, varying process noise, measurement noise, initial uncertainty of the state vector, and dimension of the state vector from d = 1 to 42. Our theory uses particle flow (like physics) to compute Bayes' rule, rather than a pointwise multiply. We do not use resampling of particles or proposal densities or importance sampling or any Markov chain Monte Carlo method. But rather, we design the particle flow with the solution of a linear first order highly underdetermined PDE, like the Gauss divergence law in electromagnetics. The talk explains what a particle filter is, and why engineers like particle filters, but we also explain the curse of dimensionality. We explain particle degeneracy and how we solve it with a simple cartoon. This talk is for normal engineers who do not have nonlinear filters for breakfast.

9092-12, Session 2

A comparison of multiple-IMM estimation approaches using EKF, UKF, and PF for impact point prediction

Ting Yuan, Yaakov Bar-Shalom, Peter K. Willett, R. Ben-Dov, S. Pollak, Univ. of Connecticut (United States)

We discuss three procedures to estimate the state of thrusting/ballistic endoatmospheric projectiles for the purpose of impact point prediction (IPP). The short observation time and the estimation ambiguity between drag and thrust in the dynamic model motivate the development of a multiple interacting multiple model (MIMM) estimator with various drag coefficient initializations. In each IMM estimator used, as the mode-matched state estimators for its thrusting mode and ballistics mode are of unequal dimensions, an unbiased mixing (UM) is required. We explore the MIMM-UM using extended Kalman filter (EKF), unscented Kalman filter (UKF) and particle filter (PF). For 30 real trajectories, the IPP based on the MIMM-UM estimation approach is carried out with a set of tuning parameters selected for the EKF, a set of tuning parameters selected for the UKF and a set of tuning parameters selected for the PF. The MIMM-UM-EKF, MIMM-UM-UKF and MIMM-UM-PF are compared based on the resulting IPP performance, estimator consistency and computational complexity.

9092-13, Session 2

Multiple-model filtering for particle tracking and classification

Stefano P. Coraluppi, Craig A. Carthel, Compunetix, Inc. (United States); Samuel J. Dickerson, NanoPhoretics, LLC (United States); Donald M. Chiarulli, Steven P. Levitan, Univ. of Pittsburgh (United States)

Dielectrophoresis is the use of non-uniform AC electric fields to control the motion of particles in a fluid [1-2]. We are developing dielectrophoresis-based technology for the classification of bacteriological pathogens. This requires high-quality detection, tracking and classification of biological cells from microscope imagery. Our multi-target tracking (MTT) is based on mature track-oriented multiple-hypothesis tracking (MHT) technology that has evolved over many years of research [3]. Performance metrics of interest include track-level optimal sub-pattern assignment (OSPA) and integrated squared distance (ISD) as discussed in [4]; the former is a natural generalization of the detection-level OSPA that has received much attention since its introduction [5]. Ultimately, what is of interest is classification performance: for this, sensitivity and specificity are the established metrics [6].

Unlike many traditional target-tracking settings, we have significant control of scenario and sensor parameters. This control includes the selection of the density and motion of particles via the choice of excitation frequencies. The frequency vs. terminal velocity profile for particles of interest is known, and may be exploited for high-performance filtering. In practice, we step through a sequence of frequencies, each for a fixed time duration.

Our baseline approach to particle classification employs a nearly-constant velocity (NCV) motion model and decoupled tracking and classification modules. On the other hand, since the frequency-excitation transition times are known, this information may be exploited for improved performance. A minor modification is to employ time-varying process noise statistics in the NCV filter. A more complex modification is to model particle motion via a generalization to the Integrated Ornstein-Uhlenbeck (IOU) process [7]. Correspondingly, this approach requires a multiple-model filtering solution, and provides a coupled particle tracking and classification solution. While this approach holds the promise of improved performance, there are some robustness concerns.

We illustrated the results of baseline and enhanced processing with synthetic and laboratory data for live and dead yeast cells. We discuss as well our plans for further analysis and testing with biological pathogens of interest.

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Conference overview

Oliver Drummond, CyberRnD, Inc. (United States)

This conference overview addresses the types of targets and the major characteristics of the data encountered in processing sensor data of these targets. The presentation summarizes why tracking these targets make the processing of this data so complex and challenging. The discussion includes a view of the algorithm state of the art, the current drivers in algorithm development, and the critical open issues. Future direction of this series of conferences is discussed and audience suggestions are invited.

9092-15, Session 3

Beyond covariance consistency: A new metric for uncertainty consistency

Joshua T. Horwood, Jeffrey M. Aristoff, Navraj Singh, Aubrey B. Poore, Numerica Corp. (United States)

A common requirement in many tracking systems is that of covariance consistency which requires the proper characterization of the covariance (statistical uncertainty) in the state of each object. In the space surveillance tracking domain, one sometimes needs to represent the full state probability density function (PDF) of certain space objects, especially in applications requiring nonlinear uncertainty propagation such as conjunction analysis. Thus, there is a need to assess uncertainty consistency; i.e., whether a modeled state PDF is consistent or realistic. We propose a new tracking metric (applicable to any tracking domain) that generalizes the covariance consistency metric based on the Mahalanobis distance to one that tests the proper characterization of the state PDF. Under weak assumptions, this new uncertainty consistency metric is a chi-squared random variable. Analogous tests for covariance consistency (both in offline simulations with multiple Monte-Carlo trials and online with real data) can be extended to use the uncertainty consistency metric, some of which are reviewed in this paper, such as Pearson's chi-squared goodness-of-fit test.

In addition, we propose a new class of "track accuracy" metrics that accounts for the uncertainty in the position estimate of an object. Rather than making uninformative statements such as "the position error is x meters," the proposed metric allows one to assert a level of confidence in the error by stating, for example, "the position error is at most x meters with probability y." Application of this metric could, for example, allow the operator to make more informed decisions based on the confidence in the position estimate.

9092-16, Session 3

IMM filtering on parametric data for multisensor fusion

Scott Shafer, Mark W. Owen, Space and Naval Warfare Systems Ctr. Pacific (United States)

In tracking, many types of sensor data can be obtained and utilized to distinguish a particular target. Commonly, kinematic information is used for tracking, but this can be combined with identification attributes and parametric information passively collected from the target's emitters. Along with the standard tracking process (predict, associate, score, update, and initiate) that operates in all kinematic trackers, parametric data can also be utilized to perform these steps and provide a means for feature fusion. Feature fusion, utilizing parametrics from multiple sources, yields a rich data set providing many degrees of freedom to separate and correlate data into appropriate tracks. Parametric radar data can take on many dynamics to include: stable, agile, jitter, and others. By utilizing a running sample mean and sample variance a good estimate of radar parametrics is achieved. However, when dynamics are involved, a severe lag can occur and a non-optimal estimate is achieved. This estimate can yield incorrect associations in feature space and cause track fragmentation or miscorrelation.

In this paper we investigate the accuracy of the interacting multiple model (IMM) filter at estimating the first and second moments of radar parametrics. This application is then combined into a complete kinematic and feature space correlator/tracker for the purpose of real-time sensor fusion. The algorithm is assessed by Monte Carlo simulation and compared against a running sample mean/variance technique. We find that the IMM approach yields a better result due to its ability to quickly adapt to dynamical systems with the proper model and tuning.

9092-17, Session 3

A comparative study of new nonlinear uncertainty propagation methods for space surveillance

Joshua T. Horwood, Jeffrey M. Aristoff, Navraj Singh, Aubrey B. Poore, Numerica Corp. (United States)

Accurate and precise characterization of state uncertainty (i.e., covariance consistency or uncertainty consistency) is needed in many fields including aeronautics and aviation, air and missile defense, and space situational awareness. The effectiveness of nonlinear filters and uncertainty propagation algorithms can be significantly enhanced through the use of appropriate coordinate systems tailored to the underlying dynamics.

We have developed an innovative approach to uncertainty representation wherein state uncertainty is represented in a newly-derived set of (non-singular) mean orbital elements that essentially absorb the so-called J2 zonal correction. As a result, uncertainty propagation becomes less nonlinear, and covariance/uncertainty consistency can be maintained for much longer periods of time (and at no additional computational cost). A method for preserving information through the nonlinear transforms of the uncertainty to and from Cartesian space is also described.

Our new approach is compared to existing methods for uncertainty representation (that utilize either Cartesian or osculating orbital elements) within the prediction step of (i) the extended Kalman filter, (ii) the unscented Kalman filter, and (iii) the newly-developed Gauss von Mises (GVM) filter. A Mahalanobis-distance-based covariance consistency metric and its generalization to the GVM distribution is used to assess the performance of the different combinations of nonlinear filters and coordinate systems, and quantifies the benefit of using the new set of mean orbital elements for representing uncertainty.

9092-18, Session 3

A method for reconstructing track error covariance from track quality index (TQI)

William D. Blair, Yanhua Ruan, Jason Kramer, Georgia Tech Research Institute (United States)

Many modern multi-sensor tracking systems rely on some form of track fusion, in which local track estimates and their associated covariances are shared among sensors. Considering the number of elements that need to be shared, bandwidth is a significant concern. To mitigate this issue in data links, a Track Quality Index (TQI) is often provided as a scalar measure of track quality. For example, TQI provides a direct means of choosing the better of two tracks for reporting. However, for challenging track correlation problems and other uses of the track data by the recipient, TQI is not sufficient to support reliable track correlation and a track covariance is needed for correlation and other applications like fire control. When a track covariance cannot be obtained from the platform with reporting responsibility (R2), generating a track covariance from the TQI becomes critical. Historically, methods for track covariance reconstruction from TQI have focused on matching the positional uncertainty. However, track correlation and other uses of track covariance need the covariance of the velocity estimates and this is where these techniques breakdown. In this paper, a novel method for reconstructing track covariance from TQI is proposed which includes velocity information and exploits the sensor target geometry information in the track history. The track covariance is formulated in the sensor coordinates prior to matching the TQI and covariance in order to achieve an estimate of the covariance for velocity. Simulation studies indicate that the proposed covariance reconstruction method exhibits superior performance compared to the traditional methods.

9092-19, Session 3

A new computational method for ambiguity assessment of solutions to assignment problems arising in target tracking

Alexander D. Mont, Aubrey B. Poore, Numerica Corp. (United States)

Many applications in target tracking involve solving an assignment problem based on likelihood ratios (such as that discussed in the work of Reid) to determine the maximum-likelihood association between two frames of data and estimating the probability that each node-to-node association (arc) is correct. The most common traditional methods for computing association probabilities, such as Murty's K-best and MCMC, are based on sampling the solution space. However, these methods do not scale well to large problems due to the exponential growth in the size of the solution space. To address this issue, we have developed a new sampling method based on cluster sampling. Given a "target arc" to compute the association probability of, our method divides the solution space into clusters of similar hypotheses, each containing one hypothesis with that arc and several without it. Our method converts a sample of the hypotheses (which can be taken through a traditional method) into a sample of the clusters, reducing the variance of the estimate. Our method can compute reasonably accurate probabilities of association even based on a "sample" consisting of the single best candidate solution, eliminating the need for a K-best solution method or MCMC sampling. We also show an implementation of our method that does not require explicitly enumerating the clusters, improving computation time even if association probabilities for many different arcs are required. We present simulation results showing that on several test problems, our method can generate far more accurate probability estimates in less time than can traditional methods.

9092-20, Session 3

The advancement of an algorithm

Darin T. Dunham, Vectraxx, Inc. (United States); Peter K. Willett, Univ. of Connecticut (United States); Terry L. Ogle, Vectraxx, Inc. (United States); Balakumar Balasingam, Univ. of Connecticut (United States)

The Probabilistic Multi-Hypothesis Tracker (PMHT) was developed in the early 1990s by Roy Streit and Tod Luginbuhl. Since that time many advances and improvements have been made to this elegant algorithm that is linearly efficient in processing as the number of targets, sensors, and clutter increases. This paper documents the many advances to the PMHT by several different contributors over the past two decades. The history continues and looks as promising as ever for this algorithm as we present the latest advancement—the Maximum Likelihood, Histogram Probabilistic Multi-Hypothesis Tracker (ML-HPMHT)—and the exciting results of this potential game-changer in tracking unresolved, dim targets in highly cluttered environments. This new algorithm detects and tracks with high accuracy targets that are unresolved in pixels or range bins.

9092-21, Session 3

Approximate calculation of marginal association probabilities using a hybrid data association model

Marcus Baum, Peter K. Willett, Yaakov Bar-Shalom, Univ. of Connecticut (United States); Ing Uwe D. Hanebeck, Karlsruher Institut für Technologie (Germany)

The calculation of marginal association probabilities is the major computational bottleneck in the Joint Probabilistic Data Association Filter (JPDAF). In this context, a variety of approximate methods have been proposed, ranging from simple ad-hoc formulas to sophisticated randomized algorithms. Recently, in [1], the so-called Bakhtiar and Alavi algorithm [2] turned out to give the most precise approximation among several state-of-the-art methods.

In this paper, we investigate improvements of the Bakhtiar and Alavi Algorithm [2]. First, we point out that the Bakhtiar and Alavi Algorithm [2] assumes the Probabilistic Multi-Hypothesis Tracker (PMHT) measurement model for the associations to be marginalized out. Second, we propose a novel systematic approximation that further exploits combinations of the JPDAF measurement model with the PMHT measurement model (a so-called hybrid association model, see [3]).

The novel method allows for a flexible adjustment between accuracy and computational complexity. In its least accurate but most efficient setting, the novel method coincides with the Bakhtiar and Alavi Algorithm [2], whose time complexity is linear in the number of measurements. Hence, with the price of a slightly higher runtime complexity, the new method can be adjusted to significantly outperform [2]. The new method is evaluated with respect to related methods in scenarios with up to 20 closely spaced objects.

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9092-22, Session 4

Range-only tracking to assist in SAR moving target processing

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Targets that move during the data collection period of a SAR appear blurred in the resulting image. The return of a typical ground vehicle can appear displaced by hundreds of meters in the cross-range (Doppler) direction from its true location in the formed image. A Maximum Likelihood Estimation (MLE) technique to determine the range and range rate of a moving target from SAR phase history data has been developed. A single set of these estimates is not sufficient to uniquely solve for the location of the moving target, but if they are fed into a tracking algorithm, the tracker can converge to the correct location after multiple observations. The implementation of automated tracking solution that localizes the target using the SAR observations is reported. Since the MLE algorithm only provides a range and range rate estimates, the position and velocity state are in the unobservable space. The developed approach compensates for the unobservability by using the SAR platform's motion relative to the target and by incorporating multiple angle bins into the initial estimate of the target's location. This is the dual of the multiple range bin concept used for angle-only tracking. The relative motion of the platform, in this case an aircraft, to that of the ground target provides enough variation that the necessary one derivative variation between platform and target to provide tracking is achieved. The implemented approach also adds a second layer of refinement to the localization. Once an initial estimate of the target is computed based on the angle bins centered about the scene bin, the process is reinitialized with a set of angle bins centered about the better estimate with a chip-sized uncertainty. This allows for a superior localization result at the computational cost of ten to fifteen re-calculations of observations.

9092-23, Session 4

ML-PMHT threshold determination and target trackability for K-distributed clutter

Steven Schoenecker, Naval Undersea Warfare Ctr. (United States); Peter K. Willett, Yaakov Bar-Shalom, Univ. of Connecticut (United States)

Recent work developed a novel method for determining clutter tracking thresholds and target trackability mea- sures for the Maximum Likelihood Probabilistic Multi-Hypothesis Tracker (ML-PMHT). Under certain "ideal" conditions, probability density functions (PDFs) for the peak points in the ML-PMHT log-likelihood ratio (LLR) could be calculated. Analyzing the clutter-induced peak PDF allowed for the calculation of a tracking thresh- old; analyzing both the target- and clutter-induced peak PDFs led to answers to fundamental questions about target trackablity. However, this work was done for a very specific and somewhat unrealistic case. It was assumed that received target amplitudes followed a Rayleigh distribution, and the target amplitude Rayleigh parameter was known and fixed. We seek to expand the clutter and target analysis framework to more realistic conditions. First, we will examine the case where the received target amplitudes still follow a Rayleigh distribution but the Rayleigh parameter is either not known or is not fixed. Secondly, and perhaps more importantly, we will examine the case where the clutter amplitudes do not follow a Rayleigh distribution at all, but instead follow a K-distribution, which has been postulated to more accurately describe "realistic" clutter. This work will provide answers to the question of, in a realistic environment, can a target be tracked?

9092-25, Session 4

Bias estimation for space-based optical sensors with targets of opportunity

Djedjiga Belfadel, Richard W. Osborne III, Yaakov Bar-Shalom, Univ. of Connecticut (United States)

Integration of space based sensors into a Ballistic Missile Defense System allows for detection and tracking of threats over a larger area than ground based sensors. This report examines the effect of sensor bias errors on the tracking quality of a Space Tracking and Surveillance System (STSS) for the highly non-linear problem of tracking a ballistic missile. The STSS constellation consists of two or more satellites for tracking ballistic targets. Each satellite is equipped with an IR sensor that provides azimuth and elevation to the target. The tracking problem is made more difficult due to a constant or slowly varying bias error present in each sensor's line of sight measurements. It is important to correct for these bias errors so that the multiple sensor measurements and/or tracks can be referenced as accurately as possible to a common coordinate system. The measurements provided by these sensors are assumed time-coincident (synchronous) and perfectly associated. We evaluate the Cram´er-Rao Lower Bound (CRLB) on the covariance of the bias estimates, which serves as a quantification of the available information about the biases. Statistical tests on the results of simulations show that this method is statistically efficient, even for small sample sizes (as few as two sensors and six points on the (unknown) trajectory of a single target of opportunity). We also show that the RMS position error is significantly improved with bias estimation compared with the target position estimation using the original biased measurements.

9092-26, Session 4

Intialization and tracking with Doppler-biased multistatic time-of-arrival measurements

Wenbo Dou, Yaakov Bar-Shalom, Peter K. Willett, Univ. of Connecticut (United States)

We discuss the multistatic target tracking problem in which the target is illuminated by Doppler tolerant waveforms (DTW). DTW introduce a bias to the true time-of-arrival, as a result of which the corresponding range measurement accuracy is degraded when this bias is ignored. An important part in the design of a tracking filter using nonlinear measurements is the initialization: the initial state estimate should be unbiased and the associated covariance should be consistent with the errors. This paper presents a maximum likelihood based method as well as a simpler iterative bias cancellation method to initialize a tracking filter from two observation frames. The iterative method makes it possible to obtain unbiased initial position and velocity estimates by canceling out the Doppler bias. Simulation results show that the filter initialized by either method is statistically consistent.

9092-27, Session WRKSP

Some fundamentals unique to multiple target tracking

Oliver Drummond, Consulting Engineer (United States)

The task of estimation of the trajectories of multiple targets using sensor measurements can exhibit fundamentals that are unique compared to other typical estimation processing. A common cause is the misassociations due to dense measurements relative to the sensor accuracy (such as the number of measurements in a three sigma measurement gate) but there can be other important causes too. The possibility of misassociations can

greatly complicate the design and development process and cause them to be uniquely complex and challenging. To simplify the discussion of these unique fundamental characteristics, much of the discussion is limited to measurements of targets that are generated by linear, Gaussian processes.

The discussion includes typical causes of the complexity, some strictly optimal design criteria, some common constrained optimal design criteria used to reduce the process complexity, and related functional performance metrics.

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9093-1, Session 1

Phenomenology of low probability of intercept synthetic aperture radar via frank codes

David A. Garren, Phillip E. Pace, Ric N. Romero, Naval Postgraduate School (United States)

This paper investigates techniques for using low probability of intercept (LPI) modulation methods for synthetic aperture radar (SAR). This analysis considers a specific waveform type based upon Frank codes in providing a phase shift keying (PSK) modulation. A matched correlation receiver is utilized to generate a set of SAR data corresponding to the transmitted Frank-modulated waveforms. The resulting two-dimensional impulse response within the SAR image is analyzed in terms of the radar parameters.

The objective of this investigation is to analyze the properties of SAR images formed using a particular LPI modulation based upon the Frank code. This analysis demonstrates the ability to form SAR images based upon simulated radar measurements collected by a notional radar sensor with a LPI-SAR capability. The SAR image formation quality and LPI performance corresponding to this PSK waveform is compared with the use of pulse waveforms and that of frequency-modulated continuous wave (FMCW) waveforms. The recent work of Giusti and Martorella [1] for generating ISAR images based upon the transmission and reception of FMCW waveforms provides a useful basis of comparison with the generation of SAR images based upon Frank-coded waveforms.

For the initial part of the simulation activity, it is necessary to generate the idealized impulse response of the scene corresponding to the radar sensor aspect and elevation angles for each radar waveform that is transmitted. The result of the ideal correlation processing is obtained by taking the convolution of the complex conjugate of the transmitted waveform with the received radar echo from the scene location where the gain of the radar transmission beam is steered for that particular waveform. These idealized radar responses give the effective impulse response of the scene at the particular aspect and depression angles of the radar sensor relative to the scene of interest.

In order to obtain an accurate model of the receiver processing, the idealized radar echo that is simulated for the interrogated scene at some particular set of aspect and elevation angles is convolved with the selected Frank-coded radar waveform used for this particular set of measurements angles. The result of this correlation receiver processing is obtained by computing the convolution of the received waveform with the complex conjugate of the transmission waveform at the set of measurement angles under interrogation. This correlation processing yields the range profile of the scene corresponding to each transmitted Frank-coded waveform along the synthetic aperture. This correlation processing effectively dispreads the radar echoes that enter the receiver, so that range profiles are extracted from the scene consistent with the sidelobe properties of Frank waveforms. The resulting complex-valued range profiles enable the generation of conventional spotlight-mode SAR images of the scene of interest. The properties of the SAR image obtained from the use of Frank-coded waveforms are analyzed and discussed.

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9093-2, Session 1

Autofocus and analysis of geometrical errors within the framework of fast factorized back projection

Jan Torgrimsson, Chalmers Univ. of Technology (Sweden); Patrik Dammert, Hans Hellsten, Saab AB (Sweden); Lars M. H. Ulander, Swedish Defence Research Agency (Sweden)

This paper describes a Fast Factorized Back-Projection (FFBP) formulation that includes an integrated autofocus algorithm, i.e. the Factorized Geometrical Autofocus (FGA) algorithm. The base-two factorization is executed in a horizontal plane, using a Merging (M) and a Range History Preserving (RHP) transform. Six parameters are adopted for each sub-aperture pair, i.e. to establish the geometry stage-by-stage via triangles in 3-dimensional space. If the parameters are derived from navigation data, the algorithm is used as a conventional processing chain. If the parameters on the other hand are varied from a certain factorization stage and forward, the algorithm is used as a joint image formation and autofocus strategy. By regulating the geometry at multiple resolution levels, challenging defocusing effects, e.g. space-variant Range Cell Migration (RCM), can be corrected. The new formulation also serves another important purpose, i.e. as a parameter characterization scheme. By using the M and RHP transform and its inverse, relations between two arbitrary geometries can be studied; in consequence this makes it feasible to analyze how errors in navigation data, and topography, affect image focus. The versatility of the factorization procedure is demonstrated successfully on simulated Synthetic Aperture Radar (SAR) data. This is achieved by introducing typical GPS-/IMU errors prior to processing. The characterization scheme is then employed to evaluate the sensitivity, to determine at what stage the autofocus function should be activated, and to decide the number of necessary parameters at each stage. A resulting FGA image is also compared to a reference image (processed without errors and autofocus) and to a defocused image (processed without autofocus), to validate the novel approach further.

9093-3, Session 1

A three-dimensional fractional Fourier transformation methodology for volumetric linear, circular, and orbital synthetic aperture radar image formation

Matthew P. Pepin, U.S. Air Force (United States)

The 3-D Fractional Fourier Transformation (FRFT) has unique applicability to multi-pass and multiple receiver Synthetic Aperture Radar (SAR) scenarios which can collect radar returns to create volumetric reflectivity data. The 3-D FRFT can independently compress and image radar data in each dimension for a broad set of parameters. The 3-D FRFT can be applied at closer ranges and over more aperture sampling conditions than other imaging algorithms. The FRFT provides optimal processing matched to the quadratic signal content in SAR (i.e. the pulse chirp and the spherical wave-front across the aperture). The different parameters for 3-D linear, circular, and orbital SAR case are derived and specific considerations such as squint and scene extent for each scenario are addressed. Example imaged volumes are presented for linear, circular and orbital cases. The imaged volume is sampled in the radar coordinate system and can be transformed to a target based coordinate system.

Advantages of the FRFT which extend to the 3-D FRFT include its applicability to a wide variety of imaging condition (standoff range and aperture sub-sampling) as well as inherent phase preservation in the images formed. The FRFT closely matches the imaging process and thus is able to focus SAR images over a large variation in standoff ranges specifically at close range. The FRFT is based on the relationship between time and

frequency and thus can create an image from an under-sampled wave-front. This ability allows the length of the synthetic aperture to be increased for a fixed number of aperture samples.

9093-4, Session 1

Doppler synthetic aperture radar interferometry

H. Cagri Yanik, Birsen Yazici, Rensselaer Polytechnic Institute (United States)

In this work, we consider a single-pass interferometric synthetic aperture radar (IFSAR) system. There are two mono-static antennas that are moving in tandem with a cross-track separation which we refer to as the baseline vector. Moreover, each antenna uses ultra-narrowband continuous waveforms (CW) as an illumination source. By using ultra-narrowband CWs, our system takes advantage of i) relatively simple-to-operate, easy-to-use, low-cost and low-power transmitters; ii) high Doppler resolution and iii) suffers less from distortion due to atmospheric effects. Our objective is to estimate the ground topography and reconstruct the ground reflectivity function. We correlate the received signal with a scaled version of the transmitted signal over a finite time window. Next, we form images for each antenna from the correlated received signals and multiply the first image with the complex conjugate of the second image to form an interferogram. This results in a novel model that relates the phase of the interferogram to the ground topography, look directions of the antennas and the baseline vector. Finally, from the phase of the interferogram, we will recover the ground topography. In the final version of the manuscript, we will present numerical experiments to demonstrate the performance of our method.

9093-5, Session 1

Polar format algorithm for SAR imaging with Matlab

Ross W. Deming, Solid State Scientific Corp. (United States)

Due to its computational efficiency, the polar format algorithm (PFA) is considered by many to be the workhorse for synthetic aperture radar (SAR) imaging. Furthermore, PFA is mainly implemented in spatial Fourier space (a.k.a "K-space"), which is a nice domain for understanding SAR performance metrics, sampling requirements, etc. In this paper, we describe the mathematics behind PFA as clearly and simply as possible, and we provide computed examples using publically released AFRL data sets. In the appendix, we include Matlab code for implementing PFA in a format which is compatible with the input/output structures used by Leroy Gorham and Linda Moore in their 2010 SPIE paper "SAR image formation toolbox for MATLAB".

9093-6, Session 1

Antenna trajectory error analysis in backprojection-based SAR Images

Ling Wang, Nanjing Univ. of Aeronautics and Astronautics (China); H. Cagri Yanik, Birsen Yazici, Rensselaer Polytechnic Institute (United States)

SAR image formation methods can be categorized into two classes: the frequency-domain or fast Fourier transform (FFT)-based image formation methods, such as the range Doppler algorithm, the chirp-scaling algorithm, etc. [1] and the time-domain Back Projection (BP) based methods. The BP-based methods have shown several advantages over the FFT-based image formation methods, including the computational efficiency, the ability to accommodate arbitrary imaging geometries, the ability to handle large aperture data, straightforward adaptation of algorithms to different SAR configurations, etc.

Both BP- and FFT-based image formation methods require accurate antenna trajectory information to form focused SAR images. Erroneous trajectory information results in blurred and degraded reconstructed images. The effect of the antenna trajectory error has been analyzed in a number of papers [2-8]. However, the effect of antenna trajectory errors for general BP-based SAR image formation has not been studied before, although a number of autofocusing methods has been proposed for BP-based SAR image formation [9, 10]. Additionally, majority of the existing studies [3-8] qualitatively describe the degradations in reconstructed SAR images; and the ones that provide quantitative analysis [2, 5], are only applicable to specific trajectory error models.

In this paper, we present a theory to analyze the positioning errors in BP-based SAR images. The theory is developed using microlocal analysis [11]. Our theory provides an explicit quantitative relationship between the trajectory error and the positioning error in BP-based SAR images. The theory is applicable to arbitrary trajectory errors in transmitting and receiving antennas, arbitrary imaging geometries, and monostatic and bistatic configurations. In the final paper, we will outline the theory in detail and present numerical simulations to demonstrate our analysis.

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9093-7, Session 1

Model-based 3D reconstruction

Chad Knight, Space Dynamics Lab. (United States); Jacob H. Gunther, Utah State Univ. (United States)

Model based processing holds many potential advantages. Several advantages of model-based processing are its natural ability to incorporate prior information into the image formation process. This capability allows for enhancing desired target features and suppressing non-desirable features. And model based processing can naturally support nontraditional sampling patterns, diverse waveforms, and geometric variations.

Examination of the rank of the forward model allows for theoretical insight into how parameter changes (like motion, waveforms, etc.) effect the rank. The rank directly corresponds to scene resolvability when the forward model is generated in the spatial domain. This leads to a natural way to examine theoretical advantages of diverse system configurations. For example changing geometries, transmit waveforms, etc. can often improve rank. And often traditional approaches like windowing in range and azimuth can degrade rank for model based processing.

Model based processing has several practical considerations that need resolved in order for wide-spread application. First the utility needs to be demonstrated on actual SAR data. Second, the problem dimension needs to be reduced to be tractable for scenes of interest, especially 3D scenes. And lastly robust models need developed that can handle model-mismatch.

This paper focuses on the GOTCHA data set and applies model based processing to actual 3D scenes and demonstrates results that show improved interpretability. Some solutions emphasize spatial smoothness, sparsity on others, and aspect smoothness to contrast results.

This problem is formulated as a convex optimization problem particularly as a second order cone program. This naturally allows for prior target information about the pixel RCS magnitude to be incorporated spatially and in aspect.

Simulated results are also demonstrated for promising potential configurations.

9093-8, Session 1

Bayesian autofocus for interrupted SAR using approximate message passing

Joshua N. Ash, The Ohio State Univ. (United States)

We consider the problem of generating focused synthetic aperture radar imagery in scenarios where the phase history data suffers from gaps in the coherent collection. In practice, such gapped collections may arise from multi-mode radars where the coherent collection over a synthesized aperture is interrupted by other services, or from wide-band collections subject to jamming or transmission constraints over sub-bands. Additionally, we consider collections suffering from motion-induced phase errors in the measurement acquisition model. Such model discrepancies in uninterrupted data generally result in defocused imagery, and correction falls to a post-processing autofocus routine. In this paper we adopt a Bayesian approach to image generation from interrupted and phase-corrupted data. The Bayesian approach maintains tractability through the use of approximate message passing and combats ill-posedness through a priori models of the scene and corrupting phase, which is modeled as von Mises Markov chain across the synthetic aperture. This approach provides posterior confidence on the output imagery and generalizes recent results in the phase retrieval literature to include partial phase information. Examples demonstrate the approach on measured and synthetic imagery.

9093-9, Session 1

Applying stereo SAR to remove height-dependent layover effects from video SAR imagery

John Miller, Edward Bishop, General Atomics Aeronautical Systems, Inc. (United States); Armin W. Doerry, Sandia National Labs. (United States)

This paper describes a correction technique using stereo Synthetic Aperture Radar (SAR) that improves the image quality of VideoSAR. The VideoSAR mode provides a persistent view of a scene centered at the Motion Compensation Point (MCP). The radar platform follows a circular flight path. The effect of height-dependent layover in VideoSAR imagery is that objects higher than the image plane appear translated towards the along-track direction in the image plane. A Digital Elevation Map (DEM) provides the height of the MCP. A height error in the MCP results in a SAR image that is not centered at the MCP. An objective is to form a sequence of SAR images centering the MCP for each image. This paper details a correlation method performed on a pair of SAR images in order to estimate the layover. Using multiple pairs of images taken from VideoSAR imagery improves the reliability of the layover estimate. Synthetic target imagery with targets at non-zero heights demonstrates the method. The paper presents 2011-2013 flight data collected by General Atomics Aeronautical Systems, Inc. (GA-ASI) implementing the VideoSAR mode with correction for layover. The flight data demonstrates good video quality with the MCP centered in each video frame.

9093-10, Session 1

The Born approximation, multiple scattering, and the butterfly algorithm

Alejandro F. Martinez, The Univ. of Texas-Pan American (United States)

Many imaging algorithms have been designed for the linearized scattering model. In the absence of multiple scattering they are efficient, and fairly accurate. In order to have a more robust imaging scheme, one needs to account for multiple scattering effects. In SAR imaging, one is typically interested in the position and motion of several targets that are some distance from our antenna. The closer the targets lie to each other, the more likely multi scattering effects become apparent in image formation. On the other hand, when one wants to test a reconstruction algorithm, they might use synthetic data. Data that does not contain multiple scattering effects will not accurately model real world scenarios. We previously discussed an algorithm for removing high order scattering components from collected data. The main failure in this work was the lack of efficient image and data creation methods. Our goal is to continue this work. First we survey the current state of multiple scattering in SAR. Then we revise our method and test it. The point is to have an algorithm that will make the approximation more valid rather than try and replace other algorithms which were designed with the Born approximation in mind. The idea is to create a coarse estimate of the target reflectivity and use it to estimate high order scattering at the point of data collection. We use the scalar wave model as the setting for electromagnetic propagation. In order to generate data, one must evaluate the scattering operator many times. Not only that, we must evaluate this operator near our targets, so far field estimates fail. This operator takes the form of a Fourier Integral Operator (FIO). Recent work has applied the butterfly algorithm to efficiently evaluate a general FIO. In more recent papers, this has been applied to SAR under the Born approximation. We apply this work to estimate high order scattering felt at the receiver. Given an estimate of our target reflectivity, we use a factored form of the Neumann series for multiple scattering combined with the butterfly algorithm to efficiently compute the multi scattering effects in our target region for various frequencies. We then propagate this energy through free space towards our antenna. A discussion of the convergence of the scattering series will be given, along with experimental evaluation of the stability of the series with respect to reflectivity function.

9093-11, Session 2

Estimation of information measures on target manifolds

Emre Ertin, The Ohio State Univ. (United States)

No Abstract Available

9093-12, Session 2

Geometric separability analysis for radar exploitation

Adam R. Nolan, Andrew J. Lingg, George S. Goley, Etegent Technologies, Ltd. (United States)

No Abstract Available

9093-13, Session 2

Feature selection using sparse Bayesian inference

James R. Baxter, T. Scott Brandes, Signal Innovations Group, Inc. (United States)

No Abstract Available

9093-14, Session 2

Geometrical prediction of SAR templates

Christopher Paulson, Edmund Zelnio, Air Force Research Lab. (United States)

No Abstract Available

9093-15, Session 2

Ship detection in SAR images using efficient land masking methods

Ahmed S. Mashaly, Ezz Farouk, Tarek Mahmoud, Military Technical College (Egypt)

Synthetic Aperture Radar (SAR) has an important contribution in monitoring ships in the littoral regions. This stems from the substantial information that SAR images have which can facilitate the ships detection operation. Coastline images produced by SAR suffer from many deficiencies which arise from the presence of speckles and strong signals returned from land and rough sea. The first step in many ship detection systems is to mark and reject the land in SAR images (land masking). This is performed to reduce the number of false alarms that might be introduced if the land is processed by ship detector. In this paper, two powerful methods for land masking are introduced. One is based on mathematical morphology while the other is based on Lee-Jurkevich coastline detection and mean estimator algorithm. From experimental results, the proposed methods give promising results for both strongly marking the land area in SAR images and efficiently preserving the details of coastlines as well.

9093-16, Session 2

Novel approach for assessing uncertainty propagation via information-theoretic divergence metrics and multivariate Gaussian Copula modeling

Brian J. Thelen, Joseph W. Burns, Michigan Tech Research Institute (United States)

No Abstract Available

9093-17, Session 2

Model-based expoitation, uncertainty, and interpretation

Eric R. Keydel, Leidos (United States)

No Abstract Available

9093-18, Session 2

Recent Improvements to the Radier Tracer Scattering Prediction Tool

Brian D. Rigling, Wright State Univ. (United States); Austin Mackey, The Ohio State Univ. (United States)

No Abstract Available

9093-19, Session 3

Estimating moving target information using single-channel SAR

Jacob H. Gunther, Josh Hunsaker, Utah State Univ. (United States); Hyrum Anderson, Sandia National Labs. (United States); Todd Moon, Utah State Univ. (United States)

This paper addresses the problem of estimating the position and velocity of moving targets using only phase history data from single-channel SAR (SC-SAR) system. For the case of rectilinear motion of target and SAR platform, Chapman, Hawes and Nord (2010) showed that many motion profiles lead to the same phase history measurement for an SC-SAR system. Therefore, uniquely identifying both the (x,y)-position and the (vx,vy)-velocity is impossible. Furthermore, many moving targets are indistinguishable from stationary targets.

In the present paper, we define equivalence classes of moving targets and show that the geometric structure of this set of equivalence classes is the cone of 2-by-2 positive semidefinite (PSD) matrices, which is parameterized by three variables. We show that the set of equivalence classes containing stationary targets is a two-dimensional sub-manifold, which is a set having measure zero. Thus, while there do exist moving target trajectories that yield the same phase histories as stationary targets, most moving targets are distinguishable from stationary targets. These findings enable us to give clarifying definitions for endo- and exo-clutter targets.

The paper goes on to study the practical application of these findings to estimating target motion. By sampling over the space of equivalence classes, we develop a linear model for the measurements that includes both the static scene and the moving targets. We formulate an optimization problem for simultaneously estimating both static and movers. Conveniently, the static scene can be estimated analytically, leaving only the moving targets to be estimated. We assume that there are a small number of moving targets (relative to the size of the scene). The sparsity of the movers is used to develop an estimation algorithm, which is evaluated on simulated data. Targets are identified up to membership in an equivalence class. Thus, while targets are not precisely localized in position and velocity, the presence of moving targets is detected. Prior information about the scene may be used to resolve the ambiguity.

9093-20, Session 3

CRB analysis of multichannel SAR with nonstationary noise

Gregory E. Newstadt, Alfred O. Hero III, Univ. of Michigan (United States); Edmund Zelnio, Air Force Research Lab. (United States)

No Abstract Available

9093-21, Session 3

Detection of moving humans in UHF wideband SAR

Thomas K. Sjögren, Lars M. H. Ulander, Per-Olov Frölind, Anders Gustavsson, Swedish Defence Research Agency (Sweden)

This paper addresses detection of moving and stationary humans in SAR images, more specifically very high resolution UHF SAR images. The main problem for detection and imaging of moving targets such as position shift and target signal smearing also applies to humans. The target smearing leads to peak signal loss, while the position shift leads to localization error. The amount of smearing depends on the speed, acceleration and movement direction of the target during the integration time. The longer the integration time, the more smearing the target will have and the more difficult the detection problem will be. Also, for longer integration times, the movement model for target eventually will be invalid. Prior experiments with truck and boats on VHF and UHF band has shown that for such targets, a movement model of a straight target track with constant speed are valid for relatively long integration times. In this paper, experimental results with stationary and moving humans in UHF wideband SAR images are presented. The experiment included humans in forest to test foliage penetration (FOPEN) ability for detecting humans. The images were generated by the UWB UHF SAR system LORA. LORA is a wideband array antenna SAR system developed at the Swedish Defence Research Agency (FOI) that is able to operate between 200MHz and 800MHz. Earlier work has shown the ability to detect stationary humans in LORA images. The early results of the new experiment indicate the ability to see moving humans in the UHF SAR images. The moving human detection performance will depend on integration time, integration angle and target dynamics. The experiment and the results with regard to the potential of moving and stationary human detection will be explained and presented in the final paper.

9093-22, Session 3

Ground vehicle ISAR for feature-aided tracking

Stephen J. Hershkowitz, Brian Lamb, Electromagnetic Systems, Inc. (United States)

No Abstract Available

9093-23, Session 3

Blind phase calibration for along-track interferometry: application to gotcha data set

Faruk Uysal, Vinay Murthy, C&P Technologies, Inc. (United States); Steven Scarborough, Air Force Research Laboratory, WPAFB (United States)

No Abstract Available

9093-24, Session 3

Circular SAR GMTI

Douglas Page, BAE Systems (United States)

No Abstract Available

9093-25, Session 3

Subband processing for grating lobe disambiguation in sparse arrays

Ryan K. Hersey, Georgia Institute of Technology (United States)

No Abstract Available

9093-26, Session 3

Extracting target shape invariants from pulsed radar data

Matthew A. Ferrara, Gregory Arnold, Matrix Research Inc. (United States); Mark Stuff, Michigan Tech Research Institute (United States); Jason T. Parker, Air Force Research Lab. (United States)

No Abstract Available

9093-27, Session 3

ISAR image-aided measurement-level radar/AIS fusion for maritime surveillance

Bhashyam Balaji, Michael K. McDonald, Anthony Damini, Christopher M. Parry, Defence Research and Development Canada (Canada)

No Abstract Available

9093-28, Session 3

An FFT-based along track interferometry (ATI) approach to SAR-based GMTI

Daniel Thomas, SRC Inc. (United States)

No Abstract Available

9093-29, Session 3

Simultaneous SAR and GMTI using ATI/DPCA

Matthew Best, Air Force Lifecycle Management Ctr. (United States); Ross Deming, Solid State Scientific Corp. (United States); Sean Farrell, Air Force Research Lab. (United States)

At the 2013 SPIE meeting, we presented GMTI detection and geo-location results from the Gotcha 2006 data set using our algorithm, which is a hybrid of along-track interferometry (ATI) and the displaced phase center antenna (DPCA) technique. These results were compared against GPS truth for the scripted vehicle target. Our presentation this year expands the use of ATI/DPCA in order to detect and geo-locate all observable moving targets in the Gotcha data, including both the scripted movers and targets of opportunity. In addition, we present a computationally efficient SAR imaging technique for computing an image of the scene of interest using the same pulses

of data we used for the GMTI processing. The GMTI detections are then overlaid on the SAR image to produce a simultaneous SAR/GMTI map.

9093-30, Session 3

Multiresolution spatio-temporal modeling of video using Kronecker PCA

Kristjan Greenewald, Univ. of Michigan (United States); Edmund Zelnio, Air Force Research Lab. (United States); Alfred O. Hero III, Univ. of Michigan (United States)

We propose a new multiway multiresolution dimension reduction method, called Kronecker PCA, for performing dimension reduction in video imagery. The method simultaneously exploits spatial and temporal information about objects in the video. Kronecker PCA performs a special type of dimensionality reduction that is adapted to spatio-temporal data and is characterized by the T frame multiframe mean mu and covariance $Sigma$ of N spatial features, e.g. pixel values. After applying Kronecker PCA standard learning methods can be reliably applied, e.g. to perform object classification over a few frames, despite small sample size. Our focus is on EO video imaging, but our methods easily generalize to other space-time modalities, e.g. thermal and radar imaging.

We use the space vs. time Kronecker PCA in the estimation of $Sigma$ as in (Greenewald et al. 2013, Tsiligkaridis et al. 2013). This approach imposes structure by modeling $Sigma$ as a sum of a few (r = separation rank) space vs. time Kronecker products. Further structure is imposed by forcing $Sigma$ to be block Toeplitz for stationarity and using the multivariate AR model to force the inverse covariance to be block banded. This imposed structure on the estimated covariance matrix significantly reduces the number of samples required for estimation. For large N and scarce training samples, we replace the arbitrary spatial covariance with a sparse multiresolution model, with the temporal dimension represented using Kronecker PCA. Our multiresolution covariance model is based on that of (Choi et al. 2010), modified for space-time data and improved computational efficiency.

The learned covariance is used to obtain spatio-temporal features which are then used for classification. Methods for the localization in space and/or time of the discriminatory values are also considered.

We apply our methods to classification tasks using a dismount video dataset and compare the results to those of existing methods.

9094-20, Session Posters-Tuesday

MINACE filter: variants of realization in 4-f correlator

Dmitry V. Shaulskiy, Nikolay Evtikhiev, Rostislav S. Starikov, Sergey N. Starikov, Evgeny Y. Zlokazov, National Research Nuclear Univ. MEPhI (Russian Federation)

Minimum Noise And Correlation Energy (MINACE) filters application provides good ability to recognize in the case of gray-scale input images of object with background noises. For fast correlation matching MINACE filters can be used in 4-f correlators as computer generated hologram (holographic filters). In this paper different variants of holographic filters realization were discussed. The results of correlation recognition with holographic MINACE filters are presented.

9094-21, Session Posters-Tuesday

Invariant correlation filters comparison for multiclass recognition of scaled objects

Petr A. Ivanov, Yaroslavl State Univ. (Russian Federation)

One of the most interesting problems in optical data processing is the problem of recognition of images with geometrical distortions at the input of image recognition system. There are several approaches to the solution of this problem; one of the most popular (especially for large size images received from satellites or airplanes) is to use an optoelectronic correlator of images. In such devices the input image is recognized by the size and location of output correlation peak. In the paper there are presented results of scaled image recognition modeling with the help of optical correlator with invariant correlation filters like MACE,GMACE,MINACE and DCCF. There was created a database that contains grayscale images with different resolution with change of scale with step of 1% and 2% in range of 50% to 150% of original image size. The image database for testing include images of true and false classes.There are presented qualitative and quantitative characteristics of output correlation peaks. Also there is provided an analysis of positive and negative side of each filter's type as for single class only scaled images recognition so for multiclass one. Also there are shown results for modeling of images with more complex distortions recognition using all mentioned types of filters.The results of modeling give a chance to use these filters successfully in such kind of recognition problems.

9094-1, Session 1

High-speed optical processing using digital micromirror device *(Invited Paper)*

Tien-Hsin Chao, Thomas T. Lu, Jet Propulsion Lab. (United States); Brian P. Walker, Georgia Institute of Technology (United States); George F. Reyes, Jet Propulsion Lab. (United States)

We have designed optical processing architecture and algorithms utilizing the DMD as the input and filter Spatial Light Modulators (SLM). Detailed system analysis will be depicted. Experimental demonstration, for the first time, will also be provided. The high-resolution, high-bandwidth provided by the DMD and its potential low cost due to mass production will enable its vast defense and civil applications.

9094-2, Session 1

A midwave compressive imaging system design for high throughput *(Invited Paper)*

Richard Shilling, Robert R. Muise, Abhijit Mahalanobis, Lockheed Martin Missiles and Fire Control (United States)

We describe the design and evaluate the performance of a compressive imaging system comprised of a 256x320 detector array sensitive to mid-wave infrared, DMD, objective & relay lenses. The irradiance of each detector element is characterized that allows a system of measurements to be made separable from other detectors. The FOV is divided into smaller areas based on the support of each detector, allowing for tractable high throughput reconstructions. Based on our previous work, we apply optimal codes subject to device constraints and give favorable results. We also include feasibility experiments for tracking using point detection codes on the compressive imaging system.

9094-3, Session 1

Recent advances in correlation filter theory and application *(Invited Paper)*

B. V. K. Vijaya Kumar, Joseph A Fernandez, Carnegie Mellon Univ. (United States); Andres Rodriguez, US Air Force Research Laboratory (United States); Vishnu Naresh Boddeti, Carnegie Mellon Univ. (United States)

This talk will review recent correlation filter developments including maximum margin correlation filters (MMCFs), zero-aliasing correlation filters (ZACFs) and multi-peak correlation filters. The paper will also discuss applications of correlation filters for biometric image matching and for key binding.

9094-4, Session 1

Performance comparison of photorefractive two-bream coupling correlator with optimal fiber-based correlators *(Invited Paper)*

Jed Khoury, Air Force Research Lab. (United States); Mohammad S. Alam, Univ. of South Alabama (United States); Partha P. Banerjee, Georges T. Nehmetallah, Univ. of Dayton (United States); Daniel M. Martin, William M. Durrant, Univ. of South Alabama (United States)

The photorefractive (PR) joint transform correlator (JTC) combines two features. The first is embedded semi-adaptive optimality which weighs the correlation against clutter and noise in the input and the second is the intrinsic dynamic range compression nonlinearity which improves several metrics simultaneously without metric tradeoff. The performance of this TBC JTC scheme is evaluated against several other well-known correlation filters that have been developed in the last three decades. The result shows that this TBC JTC is a very robust correlator in standard evaluation metrics for different sets of data.

9094-5, Session 1

Data science and analytics measurement and benchmarking *(Invited Paper)*

Ashit Talukder, National Institute of Standards and Technology (United States)

No Abstract Available

9094-6, Session 2

GPU processing for parallel image processing and real-time object recognition

Kevin Vincent, California State University (United States); Damien Nguyen, Saddleback College (United States); Brian P. Walker, Georgia Institute of Technology (United States); Thomas T. Lu, Tien-Hsin Chao, Jet Propulsion Lab. (United States)

In this paper, we present a method for reducing the computation time of Autonomous Target Recognition (ATR) algorithms through the utilization of a GPU based cluster. A selected ATR algorithm is refounded to encourage efficient communication and execution on a GPU based cluster. Such refounding includes reimplementations of Preprocessing, Feature Extraction, Classification and Correlation using NVIDIA's CUDA programming model. Dynamic workload distribution architecture ensures constant node activity for maximal throughput. This method is shown to reduce computation time of the selected ATR algorithm allowing the potential for further complexity and real-time applications.

9094-7, Session 2

Local binary patterns preprocessing for face identification/verification using the VanderLugt correlator

Thibault Napoléon, Ayman Alfalou, ISEN Brest (France)

The face recognition tasks can be divided into two categories: verification (i.e. compare two images in order to know if they represent the same person) and identification (i.e. find the identity of a person into the data-base). Several powerful face recognition methods exist, in literature, for controlled environments: constrained illumination, frontal pose, neutral expression... However, there are few reliable methods for the uncontrolled case. Optical correlation has shown its interest through relevant architectures for controlled and uncontrolled environments. Based on this architecture, we propose a novel method for verification and identification tasks under illumination variation conditions. More specifically, we optimize the performances of a correlation method against illumination changes by using and adapting the Local Binary Patterns (LBP) description. This later is widely used in the literature to describe the texture of an image. For both, target image and reference image, we begin by using a specific-Gaussians function as first step of LBP-VLC correlator. This function describes the considered image texture with 8 bits words. Then we applied the adapted LBP-VLC method. To validate our new approach, we used a simple POF filter (others correlation filters can be used). The simulations are done using the YaleB and YaleB Extended databases that contain respectively 10 and 38 identities with 64 illuminations. The results obtained reach more than 94% and 92% for the verification and 93% and 90% for the identification case. These results show the good performances of our approach of LBP-correlation methods against illumination changes.

9094-8, Session 2

Performance evaluation of photorefractive two-beam coupling joint transform correlator

Georges T. Nehmetallah, Partha P. Banerjee, Univ. of Dayton (United States); Mohammad S. Alam, Univ. of South Alabama (United States); Jed Khoury, Air Force Research Lab. (United States)

Photorefractive (PR) materials have been extensively used for numerous applications such as dynamic holography, two-beam coupling (TBC), phase conjugation, optical correlation, edge enhancement and edge enhanced correlation, etc. PR polymers offer the advantage of a low cost high gain PR medium where the gain coefficient and its direction can be changed with an applied voltage. Here, we analyze the performance of a novel optical joint transform correlator (JTC) based on TBC in a PR polymer first demonstrated by Khoury et al., JOSA B 11 2167 (1994). In PR TBC, energy exchange is possible from a strong pump beam to a weak probe beam. In TBCJTC, the spatial Fourier transform of the reference and signal images to be correlated constitutes the pump. A weak probe beam, which interacts with the pump in a PR polymer placed on the common Fourier plane in a novel 4f setup, is thereafter spatially Fourier transformed and contains the JTC of the images. The advantages of this technique over the conventional JTC (CJTC) are: enhancement of the signal-to-noise ratio (SNR) through dynamic range compression, intrinsic high pass filtering or enhancement of higher spatial frequencies, and sharpening of the correlation peak due to saturation nonlinearity for appropriate values of the PR gain and pump-probe beam ratio. Through extensive simulations of different sets of reference and signal images, we calculate relevant figures of merit such as discrimination ratio, peak-to-correlation plane energy ratio and peak-to-noise ratio, and demonstrate their dependence on the PR gain coefficient and pump-probe beam ratios.

9094-9, Session 3

A novel multitracking system for the evaluation of high-level swimmers performances

D. Benara, Thibault Napoléon, Ayman Alfalou, ISEN Brest (France); A. Verney, ACTRIS (France); P. Hellar, FFN (France)

Swimmer tracking has specific difficulties compared to the other tracking systems due to some complex problems such as occlusion (by another person, a wall or splashing), variability of the target (in appearance, lighting or behavior). To overcome these issues, we developed several mono-tracking systems based on some well-known pattern recognition techniques such as Histogram based methods, LBP descriptors and optical correlation. After several intensive tests, we noticed that this latter method has shown good performances compared to the others but it still needs an enhancement in terms of temporal coherence of the reference (the reference is not recent enough). As a solution to this problem, we propose the 3D temporal concept which relies on updating the reference by the one that gave the best correlation after a predefined time interval. Then, we noticed that the tracking may dropout after several frames because we lost the robust definition of the reference which is the first one. That is why; we propose to take advantage of the composite filter concept which is a weighted summation of several images to ensure the reliability (the first reference) and the temporal coherence (the recent reference) of the reference image. Finally, we propose a novel multi-tracking system based on the Non-Linear JTC (Joint Transform Correlator) optical correlation technique to track several potential targets which increases the chances of getting a reliable tracking system.

9094-10, Session 3

Target tracking using log-polar transform-based shifted phase-encoded joint transform correlation

Mohammed N. Islam, Worku T Bitew, The State Univ. of New York (United States)

Automatic target detection and tracking requires efficient recognition of the target pattern in variable environmental conditions. Optical joint transform correlation (JTC) has been observed to efficiently recognize a target without requiring complex optical set up. However, the classical JTC suffers from poor correlation performance, which can be improved through using different modified designs. A very successful scheme is developed employing phase-shifted and phase-encoded fringe-adjusted JTC (SPFJTC), which provides with a high discrimination between a target and non-target objects in a given scene and better utilization of the space-bandwidth resource. Further enhancement of the target detect performance can be achieved by incorporating log-polar transform in the SPFJTC technique. Log-polar transformation applied to both the reference image and the input scene can make the pattern recognition invariant to rotation and scale variations. Peak-to-side lobe ratio is measured and a threshold operation is employed to detect and track a target in an unknown input scene.

9094-11, Session 3

Performance evaluation of optimal filters for target detection and tracking using SAR imagery

Mohammad S. Alam, Univ. of South Alabama (United States); Jed Khoury, Air Force Research Lab. (United States); Partha P. Banerjee, Univ. of Dayton (United States); William M. Durant, Daniel M. Martin, Univ. of South Alabama (United States); Georges T. Nehmetallah, Univ. of Dayton (United States)

Various matched filter based architectures have been proposed over the last two decades to optimize the target detection and recognition performance. While these techniques provide excellent performance with respect to one or more parameters, a unified and synergistic approach to evaluate the performance of these techniques under the same constraints is yet to be done. Consequently, in this paper, we used a set of generalized performance metrics for comparing the performance of the recently reported matched filter based techniques using various types of infrared and SAR datasets. Test results obtained using the aforementioned datasets and performance metrics provide excellent information with respect to the suitability of existing filter based techniques for various target detection and tracking practical applications.

9094-13, Session 3

A proposed optical system for implementing the novel super-fast image processing scheme: The LPED method

Chialun John Hu, Univ. of Colorado at Boulder (United States)

LPED method, or Local Polar Edge Detection method, is a novel method the author discovered and implemented in many image processing schemes in the last 3 years with 3 papers published in this and other SPIE national conferences. It uses a special real-time boundary extraction method applied to some binary images taken by an un-cooled IR camera on some high temperature objects embedded in a cold environment background in the far field.

The unique boundary shape of each high temperature object can then be used to construct a 36D analog vector (a 36 "digit" number U, with each "digit" being a positive analog number of any magnitude). This 36D analog vector U then represents the ID code to identify this object possessing this particular boundary shape. Therefore, U may be used for tracking and targeting on this particular object when this object is moving very fast in a 2D space and criss-crossing with other fast moving objects embedded in the same field of view.

The current paper will report a preliminary optical bench design of the optical system that will use the above developed soft-ware to construct a real-time, instant-detect, instant track, and automatic targeting high power laser gun system, for shooting down any spontaneously launched enemy surface-to-air-missiles from the near-by battle ground. It uses the total reflection phenomenon in the Wollastron beam combiner and real-time monitor screen auto-targeting and firing system to implement this "instant-detect, instant-kill, SAM killer system".

9094-14, Session 4

Addressing channel noise and bit rate in a multi-channel free space optical communication system

Brian P. Walker, Georgia Institute of Technology (United States); Thomas T. Lu, Jet Propulsion Lab. (United States); Colin Costello, California State Polytechnic Univ., Pomona (United States); George F. Reyes, Tien-Hsin Chao, Jet Propulsion Lab. (United States)

In this paper, we present a method to optimize Multi-Channel Free Space Optical Communication for statically aligned transmitter-receiver pairs. Pattern recognition algorithms are employed to minimize crosstalk between pixels, and reducing the need for channel redundancy. Digitization is accomplished through comparison with several look up tables that are generated during alignment. A multi-stage encoding method is used to reduce the effects of global and local noise sources. Simulation and experimental verification of this method shows improved data rates and reduced bit error rates (BER) over previous algorithms.

9094-15, Session 4

A rotation-invariant pattern recognition using spectral fringe-adjusted joint transform correlator and histogram representation

Paheding Sidike, Theus Aspiras, Vijayan K. Asari, Univ. of Dayton (United States); Mohammad S. Alam, Univ. of South Alabama (United States)

A new rotation-invariant pattern recognition technique, based on spectral fringe-adjusted joint transform correlator (SFJTC) and histogram representation, is proposed. Synthetic discriminant function (SDF) based joint transform correlation (JTC) techniques have shown attractive performance in rotation-invariant pattern recognition applications. However, when the targets present in a complex scene, SDF-based JTC techniques may produce false detection due to inaccurate estimation of rotation angle of training images. Therefore, we herein propose an efficient rotation-invariant JTC scheme which does not require a priori rotation training of the reference image. In the proposed technique, we introduce a new modified Gaussian ringlet intensity distribution (GRID) descriptor, which is employed to obtain rotation-invariant features from the reference image. In this step, we divide the reference image into multiple ringlets and extract histogram distribution of each ringlet, and then concatenate them into a vector as a target signature. Similarly, an unknown input scene is also represented by the GRID which produces a multidimensional input image. Finally, the concept of the SFJTC is incorporated and utilized for target detection in the input scene. The classical SFJTC was proposed for detecting very small objects involving only few pixels in hyperspectral imagery. However, in our proposed algorithm, the SFJTC is applied for a two-dimensional image without limitation of the size of objects and most importantly it achieves rotation-invariant target discriminability. Simulation results verify that the proposed scheme performs satisfactorily in detecting targets in the input scene irrespective of rotation of the object.

9094-16, Session 4

Local directional pattern of phase congruency features for illumination invariant face recognition

Almabrok Essa, Vijayan K. Asari, Univ. of Dayton (United States)

Abstract:

An illumination-robust face recognition system using Local Directional Pattern (LDP) descriptors in Phase Congruency (PC) space is proposed in this paper. The proposed Directional Pattern of Phase Congruency (DPPC) is an oriented and multi-scale local descriptor that is able to encode various patterns of face images under different lighting conditions. It is constructed by applying LDP on the oriented PC images. A LDP feature is obtained by computing the edge response values in eight directions at each pixel position and encoding them into an eight bit binary number using the relative strength magnitude of these edge responses. Phase congruency and local directional pattern have been independently used in the field of face recognition and facial expression recognition, since they are robust to illumination changes and has computational simplicity. When PC extracts the discontinuities in the image such as edges and corners, the LDP computes the edge response values in different directions and uses these to encode the image texture. The local directional pattern descriptor on the phase congruency image is subjected to principal component analysis (PCA) for dimensionality reduction for fast and effective face recognition application. The performance evaluation of the proposed DPPC algorithm is conducted on several publicly available databases and observed promising recognition rates. Better classification accuracy shows the superiority of LDP descriptor against other appearance-based feature descriptors such as Local Binary Pattern (LBP). In other words, our result shows that by using LDP descriptor the Euclidean distance between reference image and testing images in the same class are much less than that between reference image and testing images from the other classes. Research work is in progress to employ 2D PCA of the DPPC descriptors for dimensionality reduction and feature representation.

Summary:

An illumination-robust face recognition system using Local Directional Pattern (LDP) descriptors in Phase Congruency (PC) space is proposed in this paper. When PC extracts the discontinuities in the image such as edges and corners, the LDP computes the edge response values in different directions and uses these to encode the image texture. The local directional pattern descriptor on the phase congruency image is subjected to principal component analysis (PCA) for dimensionality reduction for fast and effective face recognition application. Experimental results show that the proposed DPPC model is a useful approach for facial feature representation that can improve the reliability of face recognition system in natural settings.

9094-17, Session 4

A novel two-pattern full lateral resolution structured light illumination method

Minghao Wang, Laurence G. Hassebrook, Univ. of Kentucky (United States)

Structured Light Illumination is a widely used 3D shape measurement technique in non-contact surface scanning and can use one or more patterns in implementation. Multi-pattern techniques achieve both non-ambiguous and accurate measurements, but are limited to stationary objects. The Composite Pattern was introduced as a single pattern technique and modulates several Phase Measuring Profilometry patterns into a single pattern. The Modified Composite Pattern was developed based on Composite Pattern, but instead of modulation of whole patterns, it modulates individual regions of a single pattern. This Modified Composite Pattern is non-ambiguous and reduced the problem of contrast sensitivity. However, there is still a limitation in lateral resolution. In this paper, we introduce a novel two-pattern 3D depth measuring system that utilizes a MCP pattern to achieve non-ambiguity and a single sinusoidal pattern to achieve full lateral resolution. A novel quadrature processing method is introduced to achieve the full lateral resolution coupled with a fully automated and novel de-banding algorithm to achieve the 3D surface reconstruction.

9094-18, Session 4

Finding weak edges in imagery

Prakash Duraisamy, Old Dominion Univ. (United States) and Massachusetts Institute of Technology (United States); Stephen Jackson, Xiaohui Yuan, Univ. of North Texas (United States); Mohammad S. Alam, Univ. of South Alabama (United States)

Edge detection is an important process in many computer vision and image processing applications. In specific, it is employed in feature detection and extraction for identifying changes in image gradient or discontinuities. The traditional edge detection algorithms work well under sufficient contrast and fail under poor illumination, in which case weak edges exist. This paper focuses on extracting weak edges. Our proposed method detects weak edges by using image registration. Images which depict different views of weak edges are registered, which reinforces the weak edges. Experiments on a number of 2D images show that our algorithm overcomes the drawbacks of traditional edge detection algorithm and successfully find intriguing weak edges within an image.

9094-19, Session 4

Wavelet analysis for compressed image sensing using matrices

Andre U Sokolnikov, Visual Solutions and Applications (United States)

Recently, substantial efforts have been made to find an alternative approach to the Shannon sampling theorem with a method that can deal with large data sets, something for which the Shannon theorem is not easily applicable. If applied, the above approach would have to surmount difficult computational problems resulting from large data. In order to deal with the large data sets, we avoid a universal image acquisition and use wavelet matrices based on tree structures. The proposed approach allows a calculation reduction that yields a better control over the compressed image quality. The suggested technique also advocates a selective approach over the non-adaptive, random functions favored by the Shannon sampling theorem.

9095-1, Session 1

Using artificial intelligence for automating testing of a resident space object collision avoidance system on an orbital spacecraft

Jeremy Straub, The Univ. of North Dakota (United States)

Resident space objects (RSOs) pose a significant threat to orbital assets. Due to the nature of orbital mechanics and astrodynamics, when objects in orbits with different inclinations or other characteristics strike each other, they do so with a significant differences in the direction (and possibly magnitude) of their velocity vector. This makes collisions between multiple spacecraft, spacecraft and RSOs and even between RSOs quite problematic as the damage to the spacecraft is significant and the collision will generally produce a significant amount of new RSOs with various orbital characteristics which will further clutter the orbital space.

For this reason, many commercial and governmental spacecraft incorporate collision avoidance systems. These systems may act autonomously or in conjunction with ground controllers to implement maneuvers to remove the spacecraft from the path of objects that might strike it. Each maneuver draws from a limited supply of onboard fuel (the rate of consumption of which is a key factor in the lifespan of the spacecraft) and thus maneuvers which are triggered needlessly or which move the spacecraft too far out of the way (beyond a designated margin for calculation and sensing error) are highly undesirable.

The emergence of numerous kinds of smaller spacecraft incorporating (or, in some cases, testing) numerous different forms of propulsion and possessing different characteristics (e.g., location of center of mass) means that numerous different collision avoidance systems (or configurations) will be needed. These lower-cost spacecraft will, in many cases, not have around-the-clock human controllers to rely on for commanding and reviewing emergency maneuvers. They also have smaller budgets, driving a need for lower-cost techniques. Thus, there is a need for a high-reliability method for verifying and validating the performance of RSO collision avoidance systems (CASs) at minimum cost levels.

This paper presents initial work on the adaptation of a testing environment previously used for validating human proximity safety in ground robots and aerial collision avoidance for use in verifying and validating the effective and safe operations of RSO CASs. It reviews the need, presents the system and qualitatively evaluates its utility. An overview of an autonomous testing system for use in validating the performance of an orbital collision avoidance system is provided. It characterizes the benefits of performing testing using an autonomous testing system instead of performing the testing manually. A qualitative evaluation of the benefits posed by both approaches is presented.

9095-2, Session 1

Portability scenarios for intelligent robotic control agent software

Jeremy Straub, The Univ. of North Dakota (United States)

Portability scenarios are critical in designing simulation-based tests for ensuring that a piece of AI control software will run effectively across a prospective collection of craft that it is (or may in the future) required to control (for example in a multi-craft system). They are thus critical to the process of the development and testing of artificial intelligence control software. They inform software design through assisting in the resolution of tradeoffs between software capabilities, control capabilities and the processing requirements that they drive.

This paper presents an overview of the portability scenarios that are applicable to a piece of AI control software that will be required to control multiple robots with heterogeneous movement and functional control characteristics in a multi-tier architecture. For each prospective target-craft type, its capabilities, mission function, location, communications capabilities and power profile are presented and performance characteristics are reviewed. This work will inform future work related to decision making related to software capabilities, hardware control capabilities and processing requirements.

The aforementioned portability scenarios define part of the requirements for the agent control software for the multiple heterogeneous craft system. These scenarios define the: (a) different parts of the system, (b) what they do, (c) the actuators and sensors that they use to perform their mission, and (d) other key requirements and constraints of the particular craft type. These scenarios and the performance criteria are high-level specifications for assessing individual craft performance. This information is critical to software development as well as understanding the system as a whole.

9095-3, Session 1

Modeling techniques for remote sensing

Jeevake Attapattu, Ershad Sharifahmadian, Shahram Latifi, Univ. of Nevada, Las Vegas (United States)

Hyperspectral Imaging (HSI) sensors supply image data with spatial and spectral resolution which can be utilized to detect and identify desired objects in a scene. To better study the HSI sensors and remote sensing system performance, different parts of the remote sensing system can be modeled. Over the last decade, various modeling techniques have been presented in the literature. Generally, different modeling methods are employed depending on their applications such as military, meteorology, etc.

Modeling techniques which use the spatial-spectral information, have evolved from only the usage of one type of sensors (e.g. multispectral sensors), to more recent methods which utilize electro-optical and radar sensors.

Here, a scientific overview of recent modeling techniques is presented to come up with an appropriate approach for the application of target detection. Unlike current modeling methods in the literature, this study explains and assesses different aspects of modeling techniques for target detection comprehensively. In particular, this study focuses on the development in modeling of scene, sensors, and processing algorithms. Moreover, the parallelization of the methods which speeds up the process of the target detection, is considered.

With consideration of remote sensing challenges for target detection in real-world, an efficient approach for modeling of target detection is a hybrid modeling method composed of hyperspectral sensors, radars, and local sensors in which operations are done in parallel, where possible.

9095-4, Session 1

Migrating EO/IR sensor simulations to cloud-based infrastructure as a service architectures

Stephen Berglie, Steven Webster, KINEX (United States); Christopher M. May, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

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The Night Vision Image Generator (NVIG), a product of US Army RDECOM CERDEC NVESD, is a visualization tool used widely throughout Army simulation environments to provide fully attributed synthesized full motion video using physics-based sensor and environmental effects. The NVIG relies heavily on contemporary hardware-based acceleration and GPU processing techniques which push the envelope of both enterprise and commodity-level hypervisor support for providing virtual machines with

direct access to hardware resources.

The NVIG has successfully been integrated into fully virtual environments where system architectures leverage cloud-based technologies to various extents in order to streamline infrastructure and service management. This paper details the challenges presented to engineers seeking to migrate GPU-bound processes, such as the NVIG, to virtual machines and, ultimately, Cloud-Based IIAS architectures. It further presents the path that led to success for the NVIG.

A brief overview of Cloud-Based infrastructure management tool sets is provided, and several virtual desktop solutions are outlined. A discrimination is made between general purpose virtual desktop technologies compared to technologies that expose GPU-specific capabilities including direct rendering and hardware-based video encoding. Candidate hypervisor/virtual machine configurations that nominally satisfy the virtualized hardware-level GPU requirements of the NVIG are presented, and each is subsequently reviewed in light of its implications on higher-level Cloud management techniques. Implementation details are included from the hardware level through the operating system to the 3D graphics APIs required by the NVIG and similar GPU-bound tools.

9095-5, Session 2

High-fidelity modeling and simulation for compressive sensing-based receivers

Chen Wu, Sreeraman Rajan, Anne Young, Christina O'Regan, Defence Research and Development Canada (Canada)

As part of a system engineering practice, modeling and simulation should be carried out, before building and testing of systems. This engineering practice often pre-identifies performance issues so that appropriate design modifications and/or process changes can be adopted before systems are introduced into the field. The High-Fidelity RF/microwave Modeling and Simulation (RF-HFM&S) approach is one of the methods used in RF design environment to capture the high-fidelity behavioural model (HFBM) of a system to understand the system behaviour in the dynamic field conditions. Such behavioural models and simulations allow for the development of system specifications that can encompass various scenarios embedded with different operating environments.

In a previous SPIE paper, we had introduced an RF-HFM&S approach that uses System Tool Kit (STK®) with Matlab/Simulink® for wideband digital receiver development. In this paper, we build on that approach and introduce an RF-HFM&S method that adopts STK with Matlab in conjunction with SystemVue®. Further, the RF-HFM&S is demonstrated by applying it to develop the HFBM of a Compressive Sensing (CS)-based receiver.

Using the compressive sensing paradigm, a multi-channel receiving system is modeled with different antenna array configurations. The modelled multi-channel receiving system is installed on an Unmanned Aerial Vehicle (UAV) platform, and configured to intercept a ground-based emitter signal inside the simulation environment. The performance is evaluated through a scenario that is modelled in STK®.

9095-6, Session 2

MetaTracker: Integration and abstraction of 3D motion tracking data from multiple hardware systems

Ken Kopecky, Eliot Winer, Iowa State Univ. (United States)

Motion tracking has long been one of the primary challenges in mixed reality (MR), augmented reality (AR), and virtual reality (VR). Military and defense training can provide particularly difficult challenges for motion tracking, such as in the case of Military Operations in Urban Terrain (MOUT) training, live, virtual and constructive (LVC) training and other dismounted, close quarters training simulations. Advanced military training, done in this manner, can take place across large spaces, with many fast-moving objects that need to be tracked with a high degree of accuracy and low latency. Initialization, running, and maintenance of motion tracking technologies becomes a difficult challenge as more military training is done with MR, AR, and VR technologies

Many tracking technologies exist, such as optical, inertial, ultrasonic, and magnetic. Some systems even combine these technologies to complement each other. However, there are no systems that provide a high-resolution, flexible, wide-area solution that is resistant to occlusion. While frameworks exist that simplify the use of tracking systems and other input devices, none allow data from heterogeneous tracking hardware to be combined.

In this paper, a method, implemented in software, is introduced allowing multiple pieces of tracking hardware to be combined into a single system. The hardware can be from different vendors using different technologies (i.e. optical, inertial, etc.). Individual tracked objects are identified by name, and their data is provided to any simulation applications (e.g., supporting MOUT or LVC training) through a central server program. This allows tracked objects to transition seamlessly from the area of one tracking system to another. Furthermore, it abstracts away the individual drivers, application programming interfaces (APIs), and data formats for each system. Instead a single, simplified API is used to interact with data from any component of the "unified" tracking system. In addition, single, homogenous tracking systems within the unified system can themselves be tracked, allowing for real-time adjustment of their trackable area. Tracked and non-tracked areas for training simulations can be exchanged in real-time allowing simulation operators to leverage limited resources in more effective ways, and improving the quality of training. The paper will present full details on development of the method as well as implementation into software. Results will presented showing accuracy of the system as well as two formal user studies conducted for military training that took advantage of the proposed methods and software.

9095-7, Session 2

Integrated sensor architecture (ISA) for live virtual constructive (LVC) environments

Christine L. Moulton, U.S. Army Night Vision & Electronic Sensors Directorate (United States); John Harrell, Jared J. Hepp, Oakwood Controls Corp. (United States)

The Integrated Sensor Architecture (ISA) is an interoperability solution that allows for the sharing of information between sensors and systems in a dynamic tactical environment. The ISA created a Service Oriented Architecture (SOA) that identifies common standards and protocols which support a net-centric system of systems integration. Utilizing a common language, these systems are able to connect, publish their needs and capabilities, and interact with other systems even on disadvantaged networks. Within the ISA project, three levels of interoperability were defined and implemented and these levels were tested at many events. Extensible data models and capabilities that are scalable across multi-echelons are supported, as well as dynamic discovery of capabilities and sensor management. The ISA has been tested and integrated with multiple sensors, platforms, and over a variety of hardware architectures in operational environments.

Future ISA work will focus on improving the underlying mesh infrastructure to maximize efficiency and quality of service to sensors and systems. Additionally, more complex services will be implemented to enhance the initial capabilities and better anticipate the needs of a component. The computational overhead of ISA may also be further optimized to make it an attractive solution for live virtual constructive environments (LVC) that can be embedded directly into sensor hardware.

9095-8, Session 2

Mean square error performance evaluation of a commercial speckle imaging system using simulated imagery

Jeremy P. Bos, Michigan Technological Univ. (United States); Petersen F. Curt, Aryeh Kuller, EM Photonics, Inc. (United States); Michael C. Roggemann, Michigan Technological Univ. (United States)

Imagery acquired over long horizontal paths suffer from severe anisoplanatic blurring due to volume turbulence. Compensating for the non-uniform tip/tilt present in these images presents a challenge for most image reconstruction techniques. In previous works, [1][2] we evaluated the capability of speckle imaging algorithms applied to this task. Objective evaluation of reconstruction performance was enabled via the development of a horizontal imaging simulation model [3] that introduces anisoplanatic imaging distortions using phase screens with Kolmogorov statistics. We found SI techniques were able to reduce MSE by around 45% over the entire range of turbulence conditions evaluated compared to the uncompensated imagery.

The purpose of this talk is to describe the performance of commercial speckle imaging system [4] using the same process as in [1]. The simulated image sets described in [3] have been supplied to EM Photonics-the developers of the commercial system. EM Photonics will reconstruct images from the data set using their production algorithm and the results will be analyzed by the entire team. We feel that the performance of the system described and in particular the translation of research work to a commercially available product is of significant interest to the Intelligence, Surveillance, and Reconnaissance (ISR) community. This work is a collaborative effort among Dr. Jeremy Bos (formerly of Michigan Tech currently NRC postdoc at AFRL), Mr. Petersen Curt (EM Photonics), Mr. Aryeh Kuller, and Dr. Michael C. Roggemann.

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9095-9, Session 3

Knowledge fusion and continuity in disaster response service delivery systems: The integrated family assistance center model

Robert Wright, Capella Univ. (United States)

This paper examines the Aviation Disaster Family Assistance Act in terms of its policy design prescriptions that seek to improve the scope of emotional care service provided to families whose loved one was involved in an aviation disaster. The Act calls for a Family Assistance Center (FAC) to be established so that family members may obtain information concerning the status of their loved one and to receive the necessary emotional care. As based upon the insights from several public administration theories, an enhanced Model for the Act's FAC is presented – the Integrated Family Assistance Center Model. This Model is suggested as it promises to enhance the emotional care service delivery system from a service continuity perspective. Such service continuity has been found to be of value from a Critical Incident Stress Management perspective (Flannery, 1999, Wright et al., 1999). In sum, the Integrated Family Center Model is design that may enhance the overall effectiveness of the Aviation Disaster Family Assistance Act from an emergency management and disaster management vantage. Finally, several diagnostic tools are presented that may be employed at the practitioner level. These tools are designed to assess the degree to which the Integrated Family Assistance Center Model, along with its operational components, can be implemented upon activation by a specific jurisdiction through a set of knowledge fusion & remote, laser-driven, remote access technologies for overall knowledge management purposes.

9095-10, Session 3

Real aircrafts or flight simulators? What is the optimum usage in flight training?

Mustafa Cevik, Turkish Air War College (Turkey)

Flight training especially training of a fighter jet pilot is one of the most expensive, long-lasting and risky training in the World. In fact, after becoming jet pilots, training does not finish, because they are required to continue flying in order to keep their combat readiness.

Flight simulators emerged to decrease the high-costs and long time, while also keeping more pilots alive. By applications of technological developments in flight simulators, they become much more realistic and provide high fidelity and uniformity with the real aircrafts. Even these flight simulators with high fidelity can ensure better training opportunities in many aspects such as emergency procedures, repetition frequency, preparing difficult and risky conditions.

However, simulator flights can not completely supersede real flights according to many pilots. Simulator flights can help decrease real flights but there certainly has to be real flights in a specified frequency. In some training missions although simulator efficiency is far better than real flights, all missions must include some real flights.

In other words, an equation like 3 x Simulator Flight = 1 x Real Flight will never reflect the truth. There should be established an effective trade-off between simulators and real aircrafts.

This research explored the optimum usage of simulator flights and real flights in order to maintain an acceptable combat-ready status for fighter jet pilots. A questionnaire study has been applied to the end users to reach reasonable results. The participants are fighter jet pilots in Turkish Air Force. Results show that optimum usage in fighter jet flights varies depending on the category of the flown mission. Optimum usage ratios based on different main mission categories in fighter jet flights are included in results.

9095-12, Session 4

Regional value analysis at threat evaluation

Metin M. Išcan, Aykut Coskun, Harp Akademileri Komutanligi (Turkey)

It is necessary to make threat evaluation effectively in order to assign weapon at air defense management. The threat analysis which is made for defensing assets more than one or a region and for only one asset are different. Also in classical threat analysis in case of both two threats' parameters being the same, the priority is the same. In the evaluation importance of asset is ignored. When the importance of the asset is determined, it is necessary to determine the threat's target. Although it is possible to perform the target detection massive information is needed as there are too many parameters and variables. Difficulties and possibilities of providing this information makes it impossible to be more realistic target identification. Also the reliability of the model in which the threat's target detected decreases. Consequently, target detection is needed rather than any other consideration. Literature study on threat evaluation is made and a new model is put forth to eliminate the deficiency identified. At the first stage the importance degrees of targets are identified. Then regional value analysis is made according to importance of assets. As a result of analysis a regional value map is generated. The region value is given according to threat's grid. Thus, the threats having the same parameters are provided priority according to the value of their region's value. The threat evaluation made for weapon assignment is done more accurate and the possible damage is minimized.

9095-13, Session 4

Optimized design of photonic crystal-based infrared obscurants

William W. Maslin III, Univ. of Delaware (United States); Mathew J. Zablocki, James Murray, Ahmed S. Sharkawy, Lumilant, Inc. (United States); Brendan G. DeLacy, James D. Shomo, U.S. Army Edgewood Chemical Biological Ctr. (United States); Mark S. Mirotznik, Univ. of Delaware (United States)

Conventional approaches for creating effective IR obscurants have relied primarily on shaped metal particles with high aspect ratios (e.g. rods, flakes). Exploiting surface plasmon resonant (SPR) effects these particles have been shown highly effective at realizing high IR extinction coefficients per unit mass deployed. However, a disadvantage to SPR based obscurants is that they inherently scatter or absorb IR energy within a relatively narrow bandwidth. As one attempts to increase the bandwidth by designing more complicated SPR particles it always comes at the price of reducing the overall strength of the resonant absorption. In this presentation we report on an optimal design methodology for realizing all dielectric photonic crystal (PhCs) based wideband obscurants in the infrared region of the electromagnetic spectrum. The PhCs include periodic nanocavities which result in a wideband IR reflectance and a defect layer that gives rise to a narrowband transmission window. We will present an iterative optimization algorithm that integrates a rigorous electromagnetic solvers to design PhC particles with desirable spectral responses.

9095-14, Session 5

Optimization techniques for OpenCL-based linear algebra routines

Stephen T. Kozacik, Univ. of Delaware (United States); Paul A. Fox, John R. Humphrey Jr., Aryeh Kuller, EM Photonics, Inc. (United States); Dennis W. Prather, Univ. of Delaware (United States)

The OpenCL standard for general-purpose parallel programming allows a developer to target many GPUs, CPUs, co-processing devices, and FPGAs from several vendors. The computationally intense domains of linear algebra and image processing have shown significant speed-ups when implemented in the OpenCL environment. A major benefit of OpenCL is that a routine written for one device can be run across many different devices and architectures. However, a kernel optimized for one device may not exhibit high performance when executed on a different device. For this reason kernels must typically be hand-optimized for every target device family.

Due to the large number of parameters that can affect performance, hand tuning for every possible device, is impractical and often produces suboptimal results. For this work, we focused on optimizing the general matrix multiplication routine. General matrix multiplication is used as the building block for many linear algebra routines and often comprises a large portion of the run-time. Prior work has shown this routine to be a good candidate for high-performance implementation on OpenCL. We selected several candidate algorithms from the literature that are suitable for parameterization. We then developed parametrized kernels implementing these algorithms using only portable OpenCL features. Our implementation queries device information supplied by the OpenCL runtime and utilizes this as well as user input to generate a search space that satisfies device and algorithmic constraints. In our work, an exhaustive search through the entire space is used. However more advanced global optimization techniques may yield faster convergence on performant results.

Preliminary results from our work confirm that optimizations are not portable from one device to the next, and show the benefits of automatically tuning. Using a standard set of tuning parameters seen in the literature for the NVIDIA Fermi architecture achieves a performance of 1.6 TFLOPS on an AMD 7970 device, while automatically tuning achieves a peak of 2.7 TFLOPS.

9095-15, Session 5

Targeting multiple-hetergeneous hardware platforms with OpenCL

Paul A. Fox, EM Photonics, Inc. (United States); Stephen T. Kozacik, Univ. of Delaware (United States); John R. Humphrey Jr., Eric J. Kelmelis, Aryeh Kuller, EM Photonics, Inc. (United States)

The OpenCL API allows for the abstract expression of parallel, heterogeneous computing, but hardware implementations have substantial implementation differences. The abstractions provided by the OpenCL API are often insufficiently high-level to conceal differences in hardware architecture and implementations often do not take advantage of potential performance gains due to hardware limitations and other factors. These factors make it challenging to produce code that is portable in practice, resulting in much OpenCL code being duplicated for each hardware platform being targeted. This duplication of effort offsets the principal advantage of OpenCL: portability.

The use of certain coding practices can mitigate this problem, allowing a common code base to be adapted to perform well across a wide range of hardware platforms. To this end, we explore some general practices for producing performant code that are effective across platforms. Additionally, we explore some ways of modularizing code to enable optional optimizations that take advantage of hardware-specific characteristics.

The minimum requirement for portability implies avoiding the use of OpenCL features that are optional, not widely implemented, poorly implemented, or missing in major implementations. Exposing multiple levels of parallelism allows hardware to take advantage of the types of parallelism it supports, from the task level down to explicit vector operations. Static optimizations and branch elimination in device code help the platform compiler to effectively optimize programs. Modularization of some code is important to allow operations to be chosen for performance on target hardware. Optional subroutines exploiting explicit memory locality allow for different memory hierarchies to be exploited for maximum performance. The C preprocessor and JIT compilation using the OpenCL runtime can be used to enable some of these techniques, as well as to factor in hardware-specific optimizations as necessary.

9095-16, Session 5

Accelerated openCV with CUDA or openCL using ArrayFire

John M. Melonakos, AccelerEyes LLC (United States)

OpenCV is the image processing library of choice for many defense and security applications; however, it often performs too slowly for application demands. ArrayFire now supports OpenCV functionality with CUDA and OpenCL enabling GPU and OpenCL device acceleration of important image processing functions. In this presentation, benchmarks of ArrayFire's OpenCV functions will be discussed along with demos showing the OpenCV accelerated performance.

9095-17, Session Posters-Tuesday

IDS algorithm based on reinforcement learning

Jie Su, Harbin Univ. of Science and Technology (China)

In order to improve the quality of alerts in intrusion detection system (IDS), reduce the large number of redundant alarms and improve the identification and detection ability to variants of the virus, an IDS algorithm based on reinforcement learning was proposed. Deep feature representation of intrusion action is acquired by using the method of reinforcement learning to the original features of intrusion action. Then deep features generate mature detectors after tolerance exercise. Comparing with the traditional IDS based on Artificial Immune System, by extracting deep feature it overcome the arbitrariness caused by Crossover and mutation. The analysis and experiment show that this algorithm can significantly reduce the number of alerts and improve its quality, and has a high detection rate and low false detection rate.

9095-18, Session Posters-Tuesday

Distributed neural network learning algorithm

Peili Qiao, Harbin Univ. of Science and Technology (China)

This article solves the selection problem of the structural parameters, learning rate and initial weights of BP neural network. Comparing the traditional BP algorithm, this article introduces a distributed neural network learning algorithm. It improves that dynamically achieving the selection problem of input nodes, hidden layer nodes and learning rate, reducing the human factors of intervention, improving the learning rate and the adaptability of the network. The result of experiments proves that distributed neural network learning algorithm shows the better consequence than the traditional BP algorithm, with which the speed of the convergence is faster and the detection rate is higher. It not only reduces the complexity of the segmentation algorithm, but also ensures the integrity of the result of study. The trained neural network model concludes that it could accurately fit the training value and the prediction of the future trend is more accurate than the original one.

9095-19, Session Posters-Tuesday

An improved detection model for large-scale distributed network based on P2P

Peili Qiao, Harbin Univ. of Science and Technology (China)

Because existing virus detection methods using signatures to detect malicious cannot adapt to the development of virus technology, it cannot detect effectively especially for virus variants and new kind of virus. Inspired by natural immune, an improved detection model for large scale distributed network on P2P based on artificial immune and code relevance of virus is proposed. The function and realization method of each part such as feature detection, feature extraction, information fusion of this system are described in this paper. The code relevance of virus is used to extract the feature of computer virus. We match the feature code of malicious automatically by Rabin fingerprint algorithm and then adopt a distributed information fusion strategy based on computer immune and subsequence fingerprint. Al last, we propose an improved malicious code detection algorithm under distributed architecture. The method is applicable to the detection of malicious code under large scale network.

9096-1, Session 1

Q-learning and p-persistent CSMA-based rendezvous protocol for cognitive radio networks

Clifton L. Watson, Air Force Research Lab. (United States) and Michigan State Univ. (United States); Subir Biswas, Michigan State Univ. (United States)

In recent years, cognitive radio (CR) networks have emerged as a viable dynamic spectrum access (DSA) networking solution for dynamic and scarce spectrum environments. These networks are based on software-defined radio technology which equips them with the capability to sense, learn, and adapt to the spectrum environment. Within the context of DSA, CR nodes utilize this capability to opportunistically access licensed spectrum as unlicensed secondary users on the condition that little to no interference is caused to licensed primary users (PUs). To establish CR networks and thus achieve this greater flexibility and access to spectrum in a multi-channel DSA environment, CR nodes must be capable of finding each other to establish a link on a common control channel in a process known as rendezvous. We consider the blind rendezvous problem where all potentially available channels can be used to exchange data and control information without the aid of a single dedicated control channel. Several blind rendezvous schemes have been proposed in literature where each CR node is assigned a pre-defined channel hopping sequence. These sequences are built with no knowledge of the PU activity nor is some method of learning included in the rendezvous process. Consequently, the dynamics of PU activity can have a severe adverse impact on rendezvous performance. We propose a rendezvous protocol where each CR node applies both Q-learning and p-persistent CSMA to learn and visit those channels that most likely guarantee rendezvous while also controlling interference caused to PUs. Results show that the proposed protocol can enhance rendezvous performance under various levels of PU activity.

9096-2, Session 1

The UAS control segment ecosystem

Douglas A. Gregory, Neya Systems LLC (United States); Lisa K. Yarbrough, IBM Corp. (United States)

The Office of the Secretary of Defense has developed an Open Architecture (OA) and Open Business Model (OBM) for the Unmanned Aircraft System (UAS) Control Segment (UCS). The OA is the UCS Architecture, which provides service descriptions for currently 150 services and the rules of construction for extending the architecture to satisfy additional use cases. The OBM is the Ground Control Station (GCS) Open Business Model, which targets affordability and controls cost growth, incentivizes productivity and innovation in industry, and promotes real competition in the acquisition of GCS capabilities.

The OA and OBM will together contribute to the UCS Ecosystem: a network of organizations – including suppliers, distributers, customers, and government agencies – involved in the delivery of UCS products and services through both competition and cooperation. Typically each business in the ecosystem will affect and be affected by the others, creating a constantly evolving relationship in which each business must be flexible and adaptable in order to succeed.

For the UCS Ecosystem itself to be successful additional resources and interventions are necessary. This paper will discuss these within the context of the UCS Ecosystem and the broader family of net-centric systems.

Current activities include technical governance for service repositories, conformance validation methodologies, model and script support for different software development environments, and user training and helpdesk resources. In addition, the UCS data model is being mapped to adjacent architectures in the unmanned system and air domains to support data level integration within a family of systems. The UCS Architecture is also being integrated with DoD unmanned system portfolio management architectures.

Under the OBM, contracting language and contract vehicles are being established to support acquisition of UCS services, service collaborations, and complete systems within the context of the U.S. Government Better Buying Power Initiative.

9096-3, Session 1

Assessment of the integration capability of system architectures from a complex and distributed software systems perspective

Sandro Leuchter, Hochschule Rhein-Waal (Germany); Frank Reinert, Wilmuth Müller, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Procurement and design of system architectures capable of network centric operations demand for an assessment scheme in order to compare different alternative realizations. In this contribution an assessment method for system architectures targeted at the C4ISR domain is presented. The method addresses the integration capability of software intensive systems from a complex and distributed software system perspective focusing communication, interfaces and software. The aim is to evaluate the capability to integrate a system or its functions within a system-of-systems network. This method uses approaches from software architecture quality assessment and applies them on the system architecture level. It features a specific goal tree of several dimensions that are relevant for enterprise integration. These dimensions have to be weighted against each other and totalized using methods from the normative decision theory in order to reflect the intention of the particular enterprise integration effort. The indicators and measurements for many of the considered quality features rely on a model based view on systems, networks, and the enterprise. That means it is applicable to System-of-System specifications based on enterprise architectural frameworks relying on defined meta models or domain ontologies for defining views and viewpoints. In the defense context we use the NATO Architecture Framework to ground respective system models. The proposed assessment method allows evaluating and comparing competing system designs regarding their future integration potential. It is a contribution to the system-of-systems engineering methodology.

9096-4, Session 1

Proximity-based access control for context-sensitive information provision in SOA-based systems

Gowri S. Rajappan, Xiaofei Wang, Foresight Wireless, LLC (United States); Robert C. Grant, Matthew Paulini, Air Force Research Lab. (United States)

Service Oriented Architecture (SOA) has enabled open architecture integration of applications within an enterprise. For net-centric Command and Control (C2), this elucidates information sharing between applications and users, a critical requirement for mission success. But the Information Technology (IT) access control schemes, which arbitrate who gets access to what information, do not yet have the contextual knowledge to dynamically allow this information sharing to happen. The access control might prevent legitimate users from accessing information relevant to the current mission context, since this context may be very different from the context for which

the access privileges were configured. We evaluate a pair of data relevance measures – proximity and risk – and use these as the basis of dynamic access control. Proximity is a measure of the strength of connection between the user and the resource. But proximity is not sufficient, since some data might have a downside impact if leaked that far outweighs importance to the subject's mission. For this, we use a risk measure to quantify the downside of data compromise. Given these contextual measures of proximity and risk, we investigate extending Attribute-Based Access Control (ABAC), which is used by the Department of Defense, and Role-Based Access Control (RBAC), which is widely used in the civilian market, so that these standards-based access control models are given contextual knowledge to enable dynamic information sharing. Furthermore, we consider the use of such a contextual access control scheme in a SOA-based environment, in particular for net-centric C2.

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9096-5, Session 1

On investigating social dynamics in tactical opportunistic mobile networks

Wei Gao, Yong Li, The Univ. of Tennessee Knoxville (United States)

Opportunistic mobile networks consist of military mobile users who only communicate in the battlespace when they opportunistically contact each other through their short-range radios, e.g., Bluetooth or ZigBee. Understanding about the interaction between mobile communication networks and human social networks is vital to ensure efficient communication and data availability in tactical opportunistic mobile networks. This proposed work aims to foster such understanding through development of analytical models investigating the social dynamics among warfighters. Conventional wisdom considers that the social relationship among warfighters in opportunistic mobile networks is implicitly represented by their opportunistic contacts, but inappropriately formulates such relationship to be stationary over time. Ignorance of such dynamics, however, may lead to incorrect aggregation of tactical information and subsequent failure of military decisions. This proposed work aims to address these challenges, and to fundamentally transform the understanding about social relationship among warfighters from stationary and homogeneous to dynamic and heterogeneous.

Our basic idea is to formulate the social dynamics among warfighters in a probabilistic fashion, based on the experimentally validated skewness of their transient contact distributions over time. Such transient contact distributions are investigated within various network scales and time frames, so as to adaptively balance between the investigation granularity and overhead. The detailed contributions of this work are two-fold:

1) We develop quantitative models to formally depict the transient characteristics of users' social contact patterns during different short time periods. A soldier's contacts with other peers at heterogeneous times and locations are formulated based on stochastic analysis. The impact of such transient contact patterns on multi-hop opportunistic mobile communication is also analyzed.

2) We further develop various sociological metrics to formulate social dynamics among warfighers, by exploring the correspondence of sociological concepts in opportunistic mobile networks and aggregating the transient characteristics of multiple opportunistic communication links. These concepts include: i) centrality: the social importance of users' facilitating communication among other users; ii) community: users are formed into groups according to their social relations. Social dynamics are then investigated based on the variations of these metrics over time.

9096-6, Session 1

An end-to-end communications architecture for condition-based maintenance applications

Joseph B. Kroculick, Winifred Associates (United States)

Condition-Based Maintenance Plus (CBM+) is a continuous improvement initiative to improve the reliability and maintenance effectiveness of DoD systems. Extensive prognostics data for decision making is being collected at high-value platforms. Maintenance actions now generate data of interest to many interested parties including mission commanders, lifecycle management commands (LCMCs), operational data stores (ODSs) and enterprise data warehouses (EDWs).

CBM requirements are dynamic and driven by policy. For example, different platform create data needs based on how they are used in the field. Potentially, many terabytes of data can be created that would exceed the that would exceed available bandwidth of satellite link An enterprise architecture can support change by incorporating flexible rules that adapt the behavior of the architecture so that data goes to the right place.

To perform analysis of reliability data, it is essential to establish a data communications capability that moves the data from the platforms to data warehouses at the enterprise. The Army has transitioned to an Agile Acquisition Policy, known as the Agile Process, to perform brigade network modernization. Networking capabilities are developed and implemented to provide a single integrated network. This paper explores challenges in delivering an an end-to-end communications architecture for CBM+ that aligns with the Army's Network Modernization Strategy. The CBM+ communications architecture is designed to provide transport of CBM data flows from mission-critical platforms to data analysis systems and the maintenance management systems.

In a rule-driven architecture approach, the decisions on where and when to send data can be configured into the networking equipment. System rules capture the way that business is done in a specific enterprise and decision points on where to send and receive data [1]. This traceability must be maintained if business policies on maintenance change (for example, through an advisory). The location where maintenance is performed and the asset on which it is performed impacts the data pipeline since these devices are addressable [2]. The data pipeline specifies which data warehouse or operational data store to send the maintenance data in order to make a decision on when to replace an asset. The forwarding and prioritization of data flows can be expressed using system rules, a business process or both.

The main contribution of this paper is the design of an architectural design approach that connects the operational-level decisions in maintenance processes to the particular configuration of a CBM+ network communications architecture. An integrated architecture selects policy-based management components and connects them to DoDAF viewpoints for documenting rules. A data pipeline provides two-way communications from platforms that are CBM+-enabled to the enterprise-level maintenance management systems.

In this paper, we tailored the DoDAF views to support data flows and agile QoS. With a controlled language, system rules can be defined to implement data policies that then can be allocated to a traffic engineered flows in a core IP network. The integrated architecture approach that is adapted to specifying network architectures whose operational requirements are highly dynamic. Our approach uses business processes with decision points that can be constrained by system rules. The system rules then map to policies and traffic classes to build a data pipeline.

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9096-7, Session 2

RF-FPGA program overview *(Invited Paper)*

William Chappell, Defense Advanced Research Projects Agency (United States)

No Abstract Available

9096-8, Session 2

A scalable multi-input multi-output (MIMO) software defined radio platform

Hossein Hashemi, The Univ. of Southern California (United States)

No Abstract Available

9096-9, Session 2

High-power sub-1 ohm phase-change RF switching for reconfigurable RF front end

Jeong S. Moon, HRL Labs., LLC (United States)

No Abstract Available

9096-10, Session 2

Low-loss, non-volatile, phase-change RF switching technology for system reconfigurability and reliability

Mike Lee, Northrop Grumman Corp. (United States)

No Abstract Available

9096-11, Session 2

MATRICs: Micrwave array technology for reconfigurable integrated circuits

Scott Sweetland, BAE Systems (United States)

No Abstract Available

9096-12, Session 2

Low-loss millimeter-waves switches based in Vanadium dioxide metal-insulator-transition

Mark Field, Philip Stupar, Kang-Jin Lee, Teledyne Scientific Co. (United States); Mark J. Rodwell, Univ. of California, Santa Barbara (United States)

No Abstract Available

9096-14, Session 3

Integration of avionics payloads: open architecture approaches and technologies *(Invited Paper)*

Robert A, Bond, MIT Lincoln Lab. (United States); Vincent Sabio, Defense Advanced Research Projects Agency (United States)

No Abstract Available

9096-15, Session 3

Cross domaine open RF architecture *(Invited Paper)*

Betsy DeLong, Office of Naval Research (United States)

No Abstract Available

9096-16, Session 3

Manufacturing of affordable open systems for ISR *(Invited Paper)*

Dan Turner, Air Force Research Lab. (United States)

No Abstract Available

9096-17, Session 3

U.S. Navy Working Group Report: unmanned maritime system reference architecture *(Invited Paper)*

Christiane N. Duarte, Naval Undersea Warfare Ctr. (United States)

No Abstract Available

9096-18, Session 3

Empowering open systems through cross-platform interoperability *(Invited Paper)*

James C. Lyke, Air Force Research Lab. (United States)

No Abstract Available

9096-19, Session 4

Navy perspectives on open architecture unmanned systems *(Keynote Presentation)*

Mathias W. Winter, Rear Admiral, NAVAIR (United States)

No Abstract Available

9096-20, Session 4

Open architecture applied to next-generation weapons *(Keynote Presentation)*

Leo J. Rose, Air Force Research Lab. (United States)

No Abstract Available

9096-21, Session 4

General Dynamics journey in open architecture systems *(Keynote Presentation)*

Michael A. Eagan, General Dynamics Advanced Information Systems (United States)

No Abstract Available

9096-22, Session 4

Robotic collaborative technology alliance: an open architecture approach to integrated research *(Keynote Presentation)*

Robert M. Dean, Charles A. Diberardino, General Dynamics Land Systems (United States)

The Robotics Collaborative Technology Alliance (RCTA) seeks to provide adaptive robot capabilities which move beyond traditional metric algorithms to include cognitive capabilities. Research occurs in 5 main Task Areas: Intelligence, Perception, Dexterous Manipulation and Unique Mobility, Human Robot Interaction, and Integrated Research. This last task of Integrated Research is especially critical and challenging. Individual research components can only be fully assessed when integrated onto a robot where they interact with other aspects of the system to create cross-Task capabilities which move beyond the State of the Art. Adding to the complexity, the RCTA is comprised of 12+ independent organizations across the United States. Each has its own constraints due to development environments, ITAR, "lab" vs "real-time" implementations, and legacy software investments from previous and ongoing programs. We have developed three main components to manage the Integration Task. The first is RFrame, a data-centric transport agnostic middleware which unifies the disparate environments, protocols, and data collection mechanisms. Second is the modular Intelligence Architecture built around the Common World Model. The CWM instantiates a Common Data Model and provides access services. Third is RIVET, an ITAR free Hardware-In-The-Loop simulator based on 3D game technology. RIVET provides each researcher a common testbed for development prior to integration, and a regression test mechanism. Once components are integrated and verified, they are released back to the consortium to provide the RIVET baseline for further research. This approach allows Integration of new and legacy systems built upon different architectures, by application of Open Architecture principles.

SPIE. DSS DEFENSE + SECURITY

9097-1, Session 1

Applying hardware-based machine learning for detecting cyber security virus attacks

Bruce McCormick, CogniMem Technologies, Inc. (United States); Robinson E. Pino, ICF International (United States)

Cybersecurity increasingly is strategic for the protection of financial, personal, corporate, government and infrastructure data assets. Viruses and malware methods and techniques are growing in sophistication and demanding increasingly innovative solutions to detect and prevent cyber attacks. Growth in polymorphic and metamorphic virus approaches demand in situ learning and real time adaptation to address these threats. Machine learning based hardware combines the best ideas from non-linear and fuzzy algorithms powerful enough to address these threats with the performance and power advantages of specialized, but general purpose hardware. This presentation describes applying such neural based hardware trained on network traffic attack data sets and our ongoing research to extend such methods to polymorphic and metamorphic virus detection.

The technology being used is a digital based neural network utilizing Radial Basis Functions (RBF) with Restricted Coulomb Energy (RCE) learning and k Nearest Neighbor (kNN) natively implemented non-linear classifiers. Learning is done on chip at the same performance as recognition. 40,000 hardware based neurons will be used to train on network attack data and code sequences for metamorphic virus detection. The hardware technique is based on a component that accepts vector lengths up to 256 bytes and broadcasts in parallel to 40,000 parallel distance calculating neurons. A fuzzy threshold that is learned is applied to the outputs which are then submitted to a hardware search and sort for the closest result. The device can output the closest match, anomalies detected or data with firing neurons for further statistical analysis. The technology is highly scalable and can be deployed in a heterogeneous facility with traditional approaches at the server or even cost effectively at the client. Techniques for accelerating intrusion detections beyond signature-based algorithms plus handling polymorphic and metamorphic viruses will be described with empirical results.

9097-3, Session 1

Proactive malware detection and prevention

Jonathan A. Gloster, David Dredden, Mark Olsen, The Van Dyke Technology Group, Inc. (United States); Nischit Vaidya, The Van Dyke Technology Group, Inc. (United States) and Capitol College (United States); Michael Diep, The Van Dyke Technology Group, Inc. (United States) and Univ. of Maryland Univ. College (United States)

Small - to - medium sized businesses lack resources to deploy and manage high-end advanced solutions to deter sophisticated threats from well-funded adversaries, but evidence had shown that these types of business are becoming key targets. As malicious code and network attacks have become more sophisticated, classic signature-based virus and malware detection method are less effective. To augment current malware detection methods detection we have developed a proactive approach to detect emerging malware threats using open source tools and intelligence to discover patterns and behaviors of malicious attacks and adversaries. Technical and analytical skills are combined to track adversary behavior, methods and techniques.

We established a controlled (separated domain) network to identify, monitor, and track malware behavior to increase understanding of methods and techniques used by cyber adversaries. We created a suite of tools that will observe the network and system performance looking for any anomalies that may be caused by malware. The toolset collects information from open-source custom tools then provide meaningful indication that the system was under or has been attacked. Where malware is discovered we analyzed and reverse engineer to determine how it could be detected and prevented. Results have shown the resources with minimum skills are able to detect abnormal behavior that may indicate malicious software.

Research Results: The tools and techniques are packaged to provide a cost-effect method of malware detection for organizations with limited cyber security resources.

Methods, techniques to detect, defend, respond against malware

Automated Proof of Concept Methodology/workflow (lessons learned) for future research initiatives

9097-4, Session 1

On effectiveness of cryptographic mechanisms for smart grid communications

Sriharsha Mallapuram, Paul Moulema, Wei Yu, Towson Univ. (United States)

As opposed to the traditional power grid, the smart grid integrates information and communication technologies infrastructures to achieve real time control, and efficient energy source management. However, by leveraging modern communication technologies, the smart grid becomes more vulnerable and susceptible to cyber threats. Securing the smart grid is critical. For example, a successful attack can give the attacker total control on meters allowing him to compromise the data or disrupt the load balance of the system. To this end, cryptography mechanisms and key management techniques need to be in place in order to prevent and eliminate cyber attacks. Nevertheless, the overhead introduce by cryptography mechanisms in smart grid may have impact on system performance as the data from sensors and meters need to collect in real time.

Due to the joint efforts of the NIST and the Smart Grid Interoperability Panel (SGIP) led to the publication of NIST IR 7628, a critical smart grid standard deliverable that provides guidelines for utilities and their suppliers on smart grid's cyber security strategy, architecture, and high-level requirements. Based on guidelines, functional and volumetric requirements provided for communication network technologies deployment in the smart grid, we develop a co-simulation model in the Matlab Simulink environment that integrates both power grid and communication networks. Through the developed co-simulation model, we conduct simulations using real data based on use cases provided by SGIP. We systematically compare the effectiveness of diverse cryptographic techniques in securing smart grid communications and investigate their impacts on power grid operation.

9097-5, Session 1

The impact of the council of EUROPE'S convention on cyber crime on cyber security

Gökhan Bayraktar, Turkish Air War College (Turkey)

It is emerged problematic issue that how to apply international law attack in particular those committed through the use of cyber space due to the lack of discription which international actors agreed upon, of cyber space and cyber crime. This study reveals hurdles in international laws by examining crimes commited in cyberspace both in national and international envioremen, and aims to demonstrate the effectiveness of the Convention to facilitate cyber security by analyzing contribitions of the Council of Europe Convention on Cybercrime.

9097-19, Session 1

Generation of an electromagnetic field via the electro-kinetic effect and network effects

Igor V. Ternovskiy, Air Force Research Lab. (United States); Naum I. Gershenzon, Gust Bambakidis, Wright State Univ. (United States)

Here we present the results of a detailed calculation of the electric and magnetic fields induced by a Rayleigh wave due to the electro-kinetic effect. Several typical models of heterogeneity are considered, including horizontally-stratified layers and fault-like heterogeneities. The polarization and spatial distribution of the electric and magnetic fields arising from the electrokinetic effect are very specific and distinguishable from the fields generated by other sources. The results obtained could be used for the interpretation of electric and magnetic disturbances observed during an earthquake and for the prospecting of the Earth's upper crust from depths of a few meters to a few kilometers.

The co-seismic electromagnetic field contains information about the structure and physical parameters of the crust which complements that which can be obtained by purely seismic or purely electromagnetic methods. The magnitude, direction and polarization of the electromagnetic field depend on the origin of the source (i.e. piezo-magnetic effect, etc.), the type of seismic wave and the geometry of the crust.

9097-6, Session 2

Classification of group behaviors in social media via social behavior grammars

Georgiy M. Levchuk, Aptima, Inc. (United States); Lise Getoor, Univ. of California, Santa Cruz (United States); Mark Smith, Connected Action (United States)

The use of social media in facilitating information sharing and online collaboration has grown in recent years. The ease of virtual interactions has also increased the amount of criminal and anti-social activities, including social deception, cyber-attacks, industrial espionage, and riot coordination. Such activities grow not only in number, but in complexity. In virtual spaces, the criminals have more opportunities to recruit, coordinate, maintain anonymity and, hence, can easily hide their actions among a sea of normal social transactions.

The hardest to detect criminal actions are performed by groups of people who individually do not exhibit distinguishing hostile signatures and do not form normal social communities. Thus we must change the analysis focus from single actor, action, or community, - to the dynamic and heterogeneous groups of actors.

In this paper we describe a model for parsing social media data to detect and classify coordinated behaviors of multiple individuals. We combine theories of social roles and interactions with graph mining algorithms to construct social behavior grammars. These grammars capture constraints on how people take on roles in virtual environments, form groups, and interact over time, providing the building blocks for scalable and accurate multi-entity interaction analysis and social behavior hypothesis testing. Our model unified three key functions for social behavior analysis for which no adequate solutions currently exist: extraction and tracking of knowledge for implicit feature and link detection, learning frequent and anomalous person-group interaction patterns in unsupervised manner, and incorporation of external context into behavior classification.

To enable modeling diverse normal and abnormal online behaviors, our model has strong theoretic basis in the organizational structure and social behavior theories. Representing the groups and their interactions using dynamic multilayer attributed graphs enables us to model many forms of organizational structures, from functional and divisional command and control networks (Levchuk et al., 2007) to distributed resource assemblies (Levchuk et al., 2009). Multiple attributes can encode diverse dimensions of organizations; it has been shown that skills, authority, and structural stability are key variables that distinguish formal organizations (Hollenbeck, Beersma, and Schouten, 2012).

Our model extends the theories of social roles (Biddle, 1979; Lerner, 2005; Gleave et al., 2009) and person-to-person interactions to relations between groups. This allows us to represent how the behaviors of a single person are affected by other people and events, which is critical to detecting multi-actor/event coordinated behaviors and complex social dynamics. We then use probabilistic graph mining algorithms (Levchuk, Roberts, and Freeman, 2012) and group relation models to extent the grammar-based behavior representations from single-entity models (Geyik, Xie, and Szymanski, 2010) to multi-actor behavior analysis.

9097-7, Session 2

Challenges to inferring causality from viral information dispersion in dynamic social networks

John Ternovski, Univ. of Oxford (United Kingdom)

Understanding the mechanism behind large-scale information dispersion through complex networks has important implications for a variety of industries ranging from cyber-security to public health. With the unprecedented availability of public data from online social networks (OSNs) and the low cost nature of most OSN outreach, randomized controlled experiments, the "gold standard" of causal inference methodologies, have been used with increasing regularity to study viral information dispersion. And while these studies have dramatically furthered our understanding of how information disseminates through social networks by isolating causal mechanisms, there are still major methodological concerns that need to be addressed in future research. This paper delineates why modern OSNs are markedly different from traditional sociological social networks and why these differences present unique challenges to experimentalists and data scientists. The dynamic nature of OSNs is particularly troublesome for researchers implementing experimental designs, so this paper identifies major sources of bias arising from network mutability and suggests strategies to circumvent and adjust for these biases. This paper also discusses the practical considerations of data quality and collection, which may adversely impact the efficiency of the estimator. The major experimental methodologies used in the current literature on virality are assessed at length, and their strengths and limits identified. Other, as-yet-unsolved threats to the efficiency and unbiasedness of causal estimators--such as missing data--are also discussed. This paper integrates methodologies and learnings from a variety of fields under an experimental and data science framework in order to systematically consolidate and identify current methodological limitations of randomized controlled experiments conducted in OSNs.

9097-8, Session 2

The new requirement for the fifth-dimension of the war: cyber intelligence

Gökhan Bayraktar, Turkish Air War College (Turkey)

The structure and operational domain of intelligence concept have been evolving continuously in parallel to the change in threat perceptions since it became a discipline more than half a century back. The difficulties encountered in defining the Intelligence concept and its operational domain is significant barrier to construct the intelligence theory despite the steady transformation. It is observed that effective utilization of outer space and intelligence surveillance reconnaissance (ISR) functions such as electronic-war capabilities and remote detection are as important as command control system and warfare weapons in present day military expeditions with respect to comparing military operational excellence and power. Moreover, it is also noticed that nations make use of invisible attacks and cyber space as a defense system during pre-war, crisis and low intensity collisions period without employing conventional arms in addition to countries efforts to obtain new capabilities. All these developments brought a new approach to the war area. Indeed, specific intelligence started to dominate the field in comparison to conventional intelligence due to the quick progress in cyber space.

Cyber attacks, which can be classified as an asymmetric war, are not only used as a support tool to conventional wars but also considered as an independent war type on its own so that it brings a new dimension to the military operations. It is predicted that attacks in cyber space will be more dangerous than conventional assault because the usage of information technology spreads out quickly as well. Cyber attacks that usually target

the information systems of the governments` critical departments, are great threat especially for the nations, those are heavily dependent to cyber space. The importance of cyber attacks rise day by day because most of the time to detect the source of the attack is a challenging difficult task that might be initiated through a wide spectrum profiles ranging from simple individuals to complex organizations. Moreover, these attacks make a great impact despite their low cost. Furthermore, they are initiated through invisible methods where conventional weapons are not even utilized. Hence, the concept of cyber intelligence looms large against this threat.

This paper strives to explain that cyber attacks can be classified as a new type of war, because it threatens national securities and happens in cyber space that does not have any defined borders in international relations. In addition to the above, this study defines cyber intelligence concept and its operational domain as well as puts forth the methodology for consideration in order to gain the initiative in cyber attacks and to make analysis on the threat.

9097-9, Session 2

Three tenets for secure cyber-physical system design and assessment

Jeff Hughes, Tenet 3, LLC (United States); George Cybenko, Thayer School of Engineering at Dartmouth (United States)

This paper presents a threat-driven quantitative methodology for secure cyber-physical system design and assessment. Called The Three Tenets, this originally empirical approach has been used by the US Air Force Research Laboratory (AFRL) Anti-Tamper Software Protection Initiative Office for secure system research and development. The Tenets were first documented in 2005 as a teachable methodology. This paper extends that empirical work and provides a mathematical framework.

The Tenets are motivated by a system threat model that has its roots in Department of Defense Electronic Warfare Test and Evaluation (an adversarial environment with parallels to cyberspace). The threat model itself consists of three elements that must exist for successful attacks to occur:

– a system susceptibility or inherent flaw;

– a threat's access to that flaw;

– and a threat capability to exploit it.

The Three Tenets arise naturally by countering each threat element individually. Specifically, the tenets are:

Tenet 1) Focus on What's Critical

- systems should include only essential functions (to reduce susceptibility);

Tenet 2) Move Key Assets Out-of-Band

- make mission essential elements and security controls difficult for attackers to reach logically and physically (to reduce accessibility); and

Tenet) Detect, React, Adapt

- confound the attacker by implementing sensing system elements with dynamic response technologies (to counteract the attackers' capabilities).

As a design methodology, the Tenets mitigate reverse engineering and subsequent attacks on complex systems. Quantified by a Bayesian analysis and further justified by analytic properties of attack graph models, the Tenets suggest concrete cyber security metrics for system assessment.

9097-10, Session 3

Radar susceptibility to cyber attack

David Tahmoush, U.S. Army Research Lab. (United States)

Radar sensors can be viewed as a wireless network consisting of radar sensors and targets. The radar transmitter sends a communication signal to the target which then reflects it in a known pattern to the radar receivers. This type of network is susceptible to the same types of cyber attacks as a traditional wireless network, but there is less opportunity for defense. The target in the network is unable to validate its return signal, and is often uncooperative. This leads to ample opportunities for spoofing and man-in-the-middle attacks.

9097-11, Session 3

Designing resiliency

Anurag Dwivedi, Johns Hopkins Univ. Applied Physics Lab. (United States)

The motivation for this work comes from the need to improve resiliency of mission critical systems. Resiliency against adverse events, such as an attack, can be defined as the ability of a system to maintain its performance despite the occurrence of adverse events. Characterizing the resiliency of a system requires definitions of the system performance of interest and of the adverse events of concern. System resiliency requirements can be included in the design criteria.

This paper describes a methodology for designing resilient systems. The components of the methodology includes resiliency characterization, requirements mapping, subsystem ranking based on criticality, and identifying selective hardening methods to improve system resiliency to the desired levels.

Resiliency of a system can be characterized by estimating system performance degradation as a function of threat intensity. Threat intensity is expressed in terms of the number of compromised sub-systems, or the level of effort required for the compromise. Resiliency conformance is determined through an exhaustive characterization of performance degradation over all possible compromise combinations within the threat class of concern. Generally, the resiliency is poor if a low effort to compromise sub-systems can cause a significant performance degradation.

Once the non-conformance of resiliency is established, the relative criticality of a sub-system is determined based on sub-system's contribution to the loss of system performance. Such an analysis allows the identification of high criticality sub-systems, and implementation of differential hardening techniques, along with redundant architectures, to enhance the overall system resiliency to a level that meets or exceeds the requirements.

9097-12, Session 3

Modeling vulnerability, risk, and resilience in distributed control systems

Hasan Cam, U.S. Army Research Lab. (United States)

This paper presents modeling and dynamic analysis of vulnerability, risk and resilience of cyber assets and operations in a distributed cyber control system by taking advantage of control theory, decision diagram, and time Petri net. Linear time-invariant systems are used to model the target system, attacks, assets influences, and an anomaly-based intrusion detection system. Time Petri nets are used to model the impact and timing relationships of attacks, recovery and resilience operations at every node, where the transition events are triggered by alerts of intrusion detection systems. In a dynamic network environment, the number and importance of events often change, leading the criticality values of cyber assets to be changed as well. One basic requirement for a distributed control system to achieve mission success and mitigating the adverse impact of advanced threats is to measure the defense and resilience effectiveness of individual and collective cyber assets. The controllability and observability concepts of control theory are used to steer a system with compromised assets towards an uncompromised system after observing and recovering compromised assets. By integrating advantages of control theory, decision diagram, and time Petri net, this paper introduces novel approaches to modeling and assessing vulnerability, risk and resilience of cyber assets, operations and events in a distributed control system.

9097-13, Session 3

New generations of war: active defence on cyber space

Fatih Aksoy, Turkish Air War College (Turkey)

Weapon systems develop, armies change and countries need innovations on attack and defense systems with the great development of technology. As important factors, electronic and cyber battle systems are integrating with classical battle instruments and devices by the day. It is being evaluated that international contestation will focus on cyber space and security of information systems will be an important segment of national and international security.

Logistics activity and fire support of armies might be interrupted, target detection systems and mission computers might be made nonfunctional and ongoing orders might be changed with the cyber-attack to military systems. In respect of a pessimistic scenery, forthcoming elements are supposed enemy, locality control station are penetrated and satellites and drones are made out of mission. A cyber-attack to communication system influence all users of all levels. A country forces to surrender without any struggle with cyber-attacks to critical substructure as SCADA (Supervisory Control and Data Acquisition) systems. Besides all these damages, cyber-attack capability needs relatively low cost but this capability identifies countries' virtual war provision and operational advantages.

Strong password breakers, frequency mixers, faster processors, high sensitivity image sensing systems and designing and producing high-security communications satellites defines cyber war capabilities and operational advantages of countries. During the war, considering the costs of creating front-line and the loss of human, creating a virtual front-line with electronic attack as the concept of self-defenses is a strategy that in many respects superior. Physical response to the attacks of virtual armies is like fighting windmills so it needs to respond virtually to the virtual attack.

In this study, the development electronic environment, increasing dependence on cyber space, information security and cost issues, definition of cyber-security, critical infrastructures, tools and objectives of cyber threats, viruses, SCADA systems, state-sponsored cyber-attacks, cyber security policies implemented in the world and active defense issue considered as a solution for cyber defense and cyber defense policies are analyzed.

9097-2, Session 4

Robust volumetric change detection using mutual information with 3D fractals

Mark D. Rahmes, Morris Akbari, Ronda R. Henning, John Pokorny III, Harris Corp. (United States)

We discuss a robust method for quantifying change of multi-temporal remote sensing point data in the presence of affine registration errors. Three dimensional image processing algorithms can be used to extract and model an electronic module, consisting of a self-contained assembly of electronic components and circuitry, using an ultrasound scanning sensor. Mutual information (MI) is an effective measure of change. We propose a multi-resolution 3D fractal algorithm which is a novel extension to MI or regional mutual information (RMI). Our method is called fractal mutual information (FMI). This extension efficiently accounts for neighborhood fractal patterns of corresponding voxels (3D pixels).

In this paper we discuss a robust method for quantifying change without requiring affine registration, consisting of six degrees of freedom, three translations and three rotations. We consider mutual information in the fractal domain as the change detection method since it takes advantage of the fact that the entropy of a discrete distribution is invariant to rotation and translation. Our process uses an ultrasound scanner as the remote sensor to collect the volumetric data for the multilayered circuit module samples. The example is on a module but the technique is equally applicable to chips and IC's provided appropriate images are available.

The key components of this process are remote sensing, data conversion, volumetric processing and visualization. Quantification of the change between pre/post tampering applied to the volumes is desired. We leverage technology from geospatial remote sensing applications. Modeling of module features is very similar to modeling surface scenes from Light Detection and Ranging (LiDAR) or Interferometric Synthetic Aperture Radar (IFSAR) aerial data collections.

9097-14, Session 4

Main control computer (MCC) security model for intranet protection against cyber attacks

Bilal Seymen, Münir Gedikli, O?uz Sayin, Turkish Air War College (Turkey)

Controlling data input/output to provide system's maintenance safely in intranet, it's a controlling data flow model via Main Control Computer (MCC) for controlling network traffic against cyber attacks. Thanks to designed system for providing input and output data safely to network system for network users, centralized network aims to minimize security disadvantages. Besides, via storage units which are assigned to each user, data input/output register can be recorded and if it is requested, history tracing can be done. Owing to the fact that cyber security for each computer in network requires high cost, with MCC's up-to-date hardware, this security model only aims to provide cost-effective work environment.

9097-15, Session 4

Improvements of cyber space and affects to the battlefield

Münir Gedikli, O?uz Sayin, Bilal Seymen, Turkish Air War College (Turkey)

Wars previously being executed at land and sea have also become applicable in air and space due to the advancements of aircraft and satellite systems. Rapid improvements in information technologies have triggered the concept of Cyber space which is considered as the fifth dimension of war. While transporting the information quickly from physical area to electronic/digital area, Cyber space has caused to emerge a lot of threats and methods like cyber attack, cyber crime, cyber war which are spreading too rapidly. Individuals, institutions and establishments have begun to take their own cyber security precautions to cope with these threats.

This study gives information about the concepts and advances in cyber in order to raise comprehensive awareness. The study also focuses on the affects of these improvements to the battlefield and analyzes them.

9097-16, Session 4

Defending against advanced targeted attacks in the healthcare ecosystem

Stephen Bono, Independent Security Evaluators (United States)

No Abstract Available

9097-17, Session 4

Efficient non-resonant absorption of electromagnetic radiation in thin cylindrical targets: experimental evidence

Andrey Akhmeteli, LTASolid Inc. (United States); Nikolay G. Kokodiy, Boris Safronov, Valeriy Balkashin, Ivan Priz, V.N. Karazin Kharkiv National Univ. (Ukraine); Alexander Tarasevitch, Univ. Duisburg-

Essen (Germany)

A theoretical possibility of non-resonant, fast, and efficient (up to 40 percent) heating of very thin conducting cylindrical targets by broad electromagnetic beams was predicted in [Akhmeteli, arXiv:physics/0405091 and 0611169] based on rigorous solution of the diffraction problem. The diameter of the cylinder can be orders of magnitude smaller than the wavelength (for the transverse geometry) or the beam waist (for the longitudinal geometry) of the electromagnetic radiation. This can be used for numerous applications, such as pumping of active media of short-wavelength lasers, e.g., through efficient heating of nanotubes with laser radiation. Experimental confirmation of the above results is presented [Akhmeteli, Kokodiy, Safronov, Balkashin, Priz, Tarasevitch, arXiv:1109.1626 and 1208.0066]. Significant (up to 6%) absorption of microwave power focused on a thin fiber (the diameter is three orders of magnitude less than the wavelength) by an ellipsoidal reflector is demonstrated experimentally. For the longitudinal geometry, preliminary experiments provide a qualitative confirmation of significant absorption of the power of a wide CO2 laser beam propagating along a thin wire (the diameter of the wire can be orders of magnitude less than the beam waist width).

9097-18, Session 4

Micromirror array simulation and far-field diffraction analysis

Xiaohui Yuan, Siyuan Liu, Univ. of North Texas (United States); Jason D. Schmidt, MZA Associates Corp. (United States); Igor Anisimov, Air Force Research Lab. (United States)

No Abstract Available

9097-20, Session 4

Image reconstruction from sub-apertures of circular spotlight SAR

Xiaohui Yuan, Univ. of North Texas (United States); Igor V. Ternovskiy, Air Force Research Lab. (United States)

No Abstract Available

9097-21, Session 4

Classification for wireless covert timing channel communications: a geometric approach

Dung N. Tran, Johns Hopkins Univ. (United States); Peter Chin, Draper Lab. (United States)

Geometric multi-resolution analysis (GMRA), recently introduced by Allard et al. [1], aims to learn data-dependent dictionaries on general point cloud data. When the input data lies around a low dimensional manifold, GMRA has guarantees on the dictionary size and the sparsity of the representations for a given approximation error, on the computational complexity of the construction, and on the associated fast transforms mapping data points to sparse coefficients and vice versa. We propose an algorithm for classifying the data which is assumed to lie around a low dimensional set M embedded in a high dimensional ambient space R^D, based on GMRA construction on the data set.

9097-22, Session 4

No-hardware-signature cybersecurity-crypto-module: a resilient cyber defense agent

Yasser A. Zaghloul, Consultant (United States); Abdel Rahman M. Zaghloul, ITR Technologies, Inc. (United States)

We present an optical cybersecurity-crypto-module as a resilient cyber defense agent. It has no hardware signature since it is bitstream reconfigurable, where single hardware architecture functions as any selected device of all possible ones of the same number of inputs. For a two-input digital device, a 4-digit bitstream of 0s and 1s determines which device, of a total of 16 devices, the hardware performs as. Accordingly, the hardware itself is not physically reconfigured, but its performance is. Such a defense agent allows the attack to take place, rendering it harmless. On the other hand, if the system is already infected with malware sending out information, the defense agent allows the information to go out, rendering it meaningless. The hardware architecture is immune to side attacks since such an attack would reveal information on the attack itself and not on the hardware. This cyber defense agent can be used to secure a point-to-point, point-to-multipoint, a whole network, and/or a single entity in the cyberspace. Therefore, ensuring trust between cyber resources. It can provide secure communication in an insecure network. We provide the hardware design and explain how it works. Scalability of the design is briefly discussed.

9098-1, Session Key

Development and application of fiber optic sensors for power and energy systems *(Keynote Presentation)*

Susan M. Maley, U.S. Dept. of Energy (United States); Robie Lewis, National Energy Technology Lab. (United States)

The power and energy sectors are large markets with significant pressure to achieve high system and environmental performance. Monitoring key parameters in these systems requires the use of instrumentation and sensors able to withstand harsh environments and provide the necessary measurements for control and monitoring of a system's performance. Fiber optic sensors, specifically those fabricated with high temperature optical materials and robust sensor designs, are well suited to provide accurate measurements in a reliable and cost competitive manner when compared with existing instrumentation which has been shown to inadequate for harsh conditions. In addition to harsh environment monitoring, novel designs using optical fibers in concert with signal processing are enabling low cost distributed sensing to be realized for a variety of process parameters. These approaches enable a higher number of process points and parameters to be monitored at qualitatively lower cost than traditional point sensors. Distributed sensing also enables the longer term goal of 3-D reconstruction of a process based on a high number of monitoring points. The Sensors and Controls Program, operating under the National Energy Technology Laboratory and the Department of Energy's Office of Fossil Energy, is supporting research in these areas and is in collaboration with universities and industry to develop such innovative technologies. The motivation to develop fiber optic-based sensor technologies along with the various research and development efforts currently underway in these areas will be reviewed.

9098-2, Session 1

Brief history of fiber optic sensing in the oil field industry *(Invited Paper)*

Christopher S. Baldwin, Weatherford International Ltd. (United States)

The use of fiber optic sensing in the oil and gas industry has greatly expanded over the past two decades. Since the first optical fiber-based pressure sensor was installed in a well in 1993, the industry has sought to use fiber sensing technology to monitor in-well parameters. Through the years, optical fiber sensing has been used in an increasing number of applications as technical advances have opened the door for new measurements. Today, fiber optic sensors are routinely used to measure temperature throughout the wellbore. Optical fiber sensors also provide pressure measurements at key locations within the well. These measurements are used to verify the integrity of the well and to monitor the production process. Other sensors, such as seismic monitors and flow meters, use fiber sensing technology to make in-well measurements. Various optical sensing techniques are used to make these measurements, including Bragg grating, Raman scattering, and coherent Rayleigh scattering. These measurements are made in harsh environments, which require rugged designs for optical cable systems and instrumentation systems. Some of these applications have operating temperatures of 572°F (300°C), and other applications can have pressures in excess of 20,000 psi (1,379 bar). This paper provides a historical perspective on the use of fiber optic sensing in the oil and gas industry. Topics covering industry firsts to current applications will be discussed.

9098-3, Session 1

Downhole fiber optic sensing: the oilfield service provider's perspective: from the cradle to the grave

Neal G. Skinner, John L. Maida Jr., Halliburton Energy Services (United States)

For almost three decades, there has been increasing interest in the application of fiber optic sensing techniques for the upstream oil and gas industry. We review optical sensing technologies that have been and are being adopted in the oilfield and their drivers. We will briefly describe the life of a well, from the cradle to the grave and the roles fiber optic sensing can play in optimizing production, safety and protection of the environment. We describe the performance expectations (accuracy, resolution, stability and operational lifetime) that the oil companies and the oil service companies have for fiber optic sensing systems. We also describe the environmental conditions (high hydrostatic pressures, high temperatures, shock, vibration, crush, and chemical exposure) that these systems must tolerate in order to provide reliable and economically attractive oilfield monitoring solutions.

9098-4, Session 1

Get smart, go optical: example uses of optical fibre sensing technology for production optimisation and subsea asset monitoring

Chris Staveley, Smart Fibres Ltd. (United Kingdom)

Smart Fibres is a UK company developing fiber Bragg grating monitoring systems for numerous harsh environment industries including Oil & Gas, aerospace and renewable energy. The presentation will provide an overview of the systems in development, and then focus on one particular Oil & Gas application, that of a fibreoptic condition monitoring system (CMS) for a multiphase deepwater twin screw pump and associated electrical motor developed by Flowserve. Under a Shell contract, Smart Fibres designed, manufactured and installed a multi-parameter CMS, which reported motor stator temperatures, rotor bearing loads and accelerations, and lube oil pressures and temperatures. The presentation will show data collected from the CMS during performance mapping of the pump and motor on a Flowserve multiphase test loop. Analysis will be presented of the dynamic data collected from the rotor bearings which, when processed by project partner SKF, highlighted very early stage damage, which was undetectable using conventional instrumentation. The implication of such a detection capability to the oil & gas industry, and broader industry application will be considered.

Some unexpected early stage damage detected by the system will be presented.

9098-5, Session 1

Design and performances of a high temperature/ high pressure, Hydrogen tolerant, bend insensitive single-mode fiber for downhole seismic systems and applications

Andy M. Gillooly, Aurelien Bergonzo, Sudhendu Kashikar, Laurence Cooper, Fibercore Ltd. (United Kingdom)

The oil & gas exploration and production industry is facing continuous pressure to become more efficient in well discovery and to improve recovery rates. In order to meet these new requirements, sensors need to go deeper into more inhospitable wells where high pressures, high temperatures, deep

water and highly corrosive gasses can be expected. In order to tackle these challenges, advanced solutions based on optical fiber technologies have demonstrated good results for applications such as Distributed Temperature Sensing (DTS) down-hole sensors for 3D/4D seismic surveying.

Up until now, the market has been limited in fiber choice for the bend insensitive fibers, typically requiring a germanosilicate core to offer the large refractive index step suitable for coiled sensors. Whilst the germanosilicate core gives very low bend losses, it is also prone to hydrogen ingress, limiting lifetime in high temperature, high pressure, hydrogen rich wells and boreholes.

In this paper, we will present the design and performance of an optical fiber with a glass chemistry suitable for hydrogen rich environments, a coating protection suitable for continuous operation at 300oC, with bend loss more than 1500x lower than specified in G.657.A3 with excellent lifetime figures.

This new fiber offers dramatically lower hydrogen darkening for coiled fiber optic seismic sensors than has been previously accessible. Thus giving the opportunity of using these sensors in deeper and more inhospitable environments and getting physically closer to the location where the high quality data is required.

9098-6, Session 1

Real-time hydraulic fracture monitoring, a distributed acoustic sensing solution

Peter Hayward, Alan Yau, Fotech Solutions Ltd. (United Kingdom)

Details are provided of the successful implementation of an optical-fibre based distributed acoustic sensing (DAS) system, for the application of real-time monitoring of hydraulic fracturing operations in an unconventional gas well.

A Rayleigh based DAS interrogator was connected to a standard single-mode optical fibre, deployed along the entirety of the wellbore casing. Acoustic data was acquired for the whole well, for the duration of operations. A spatial sampling resolution of 0.67m was achieved with an acoustic sampling rate of up to 20kHz.

Real-time and post processed results are presented for all aspects of the fracture operations, from deployment of the frac ball, through valve operation, to fracture stage completion. Examples are provided for both successful and unsuccessful stage operations. Evidence of unsuccessful stage operation is provided by means of results identifying, incorrect valve operation, ball failures, and cement washout. Each of which are shown to exhibit a unique sequence of acoustic signals. Evidence of successful stage operation is provided by way of results identifying the detection of wave fronts associated with seismic signals propagating from the physical fracturing of the localised formation. Effectiveness of fracture operations can thereafter be ascertained as a result of assessing the relative distribution and density of such detected wave clusters.

This paper thus highlights potential benefits of utilising a DAS solution for real-time fracture monitoring. With real-time information provided to an operator that potentially allows for the optimisation of fracturing parameters on an ongoing basis, thus potentially minimising resources required on each stage of operation.

9098-7, Session 2

High-speed structural sensing using fiber grating sensors *(Invited Paper)*

Eric Udd, Columbia Gorge Research (United States)

This paper looks at very high speed monitoring using fiber optic grating sensors with an emphasis on composite materials.

9098-8, Session 2

Development of a long gauge vibration sensor

Peter Kung, QPS Photronics Inc. (Canada); Maria Cominici, McGill Univ. (Canada)

Recently, we found that by terminating a long length of fiber of up to several kilometers with an in-fiber cavity structure, the entire structure can detect vibrations over a frequency range from 5 Hz to 100 Hz. We want to determine whether the structure (including packaging) can be optimized to detect vibrations at even higher frequencies. The structure can be used as a distributed vibration sensor mounted on large motors and other rotating machines to capture the entire frequency spectrum of the associated vibration signals, and therefore, replace the many accelerometers, which add to the maintenance cost. This will replace the many accelerometers used for maintenance. Similarly, it will help detect in-slot vibrations inside an air cooled generator which causes intermittent contact leading to sparking under high voltages. However, that will require the sensor to detect frequencies associated with vibration sparking, ranging from 6 kHz to 15 kHz. Then, at even higher frequencies, the structure can be useful to detect acoustic vibrations (30 kHz to 150 kHz) associated with partial discharge (PD) in generators and transformers. Detecting lower frequencies in the range 2 Hz to 200 Hz makes the sensor suitable for Seismic studies and falls well into the vibrations associated with rotating machines. Another application of interest is corrosion detection in large re-enforced concrete structures by inserting the sensor along a long hole drilled around structures showing signs of corrosion. The frequency response for the proposed long gage vibration sensor depends on packaging

9098-9, Session 2

Ultrahigh-speed fiber optic strain measurements based on rapid edge-filter monitoring of fiber grating spectra

Brian J. Soller, Todd C. Haber, Micron Optics, Inc. (United States)

In this paper, we describe the results of ultra high-speed fiber optic strain measurements based on 2MHz sampling of the center wavelength of a fiber Bragg grating over 50nm of optical bandwidth. Steel on reinforced-concrete impact measurements were conducted and showed the ability to measure up to +/- 20,000 microstrain in as little as a few microseconds resulting in, to our knowledge, the fastest fiber optic measurement of strain based on Bragg grating technology reported to date. The instrumentation architecture is based on using a linear analog edge filter to very rapidly monitor the center wavelength of a fiber Bragg grating. System architecture and data analysis are described in detail. We also discuss the benefits of the fiber optic measurement approach over electronic sensors specifically as it relates to high-speed blast and impact measurements.

9098-10, Session 2

High-speed fiber grating pressure sensors

Eric Udd, Columbia Gorge Research (United States); George Rodriguez, Richard L. Sandberg, Los Alamos National Lab. (United States)

This paper summarizes work that has been performed in the 2007 to 2013 time frame to measure pressure and temperature with time resolution of a few nanoseconds and pressures that are greater than 1,000,000 psi.

9098-11, Session 3

High-pressure sensing and dynamics using high-speed fiber Bragg grating interrogation systems

George Rodriguez, Richard L. Sandberg, Dana M. Dattelbaum, Los Alamos National Lab. (United States); Eric Udd, Columbia Gorge Research (United States); Brandon Lalone, National Security Technologies, LLC (United States); Bruce Marshall, National Security Technologies, LLC (United States) and Special Technologies Lab. (United States)

Fiber Bragg gratings (FBGs) are developing into useful sensing tools for measuring high pressure dynamics in extreme environments under shock loading conditions. Approaches using traditional FBG interrogation systems are often limited to readout speeds in the sub-MHz range. For shock wave physics, required detection speeds approaching 100 MHz are desired. We explore the use of two types of FBG sensing systems that are aimed at applying this technology as embedded high pressure probes for transient shock events. Both approaches measure time resolved spectral shifts in short (<2 mm long) uniform FBGs at 1550 nm. In the first approach, we use a fiber coupled spectrometer to demultiplex output spectral channels into an array (up to 12) of single element InGaAs photoreceivers. By monitoring the detectors during a shock impact event with transient recording, we are able to track the pressure induced spectral shifting in FBG down to a time resolution of 20 ns. Tests show that the gratings survive to pressures approaching 50 kbar. In the second approach, a coherently mode-locked fiber laser is used to illuminate the FBG sensor. After the sensor, wavelength-to-time mapping is accomplished with a chromatic dispersive element, and entire spectra are sampled using a single detector at the modelocked laser repetition rate of 80 MHz. By sampling with a 20 GHz InGaAs detector, direct wavelength mapping in time is recorded, and the pressure induced FBG spectral shift is sampled at 80 MHz. In our presentation we describe these approaches and demonstrate their use in shock driven experiments.

9098-12, Session 3

Design and implementation of an FBG emulator for a scanning laser based fiber optic interrogator

Nader Kuhenuri Chami, Philipp Putzer, Technische Univ. München (Germany); Andreas Hurni, Kayser-Threde GmbH (Germany); Johannes Obermaier, Technische Univ. München (Germany); Sebastian M. Schweyer, Kayser-Threde GmbH (Germany); Alexander W. Koch, Technische Univ. München (Germany)

Hybrid Sensor Bus is a space-borne temperature monitoring system for telecommunication satellites combining electrical and fiber-optical FBG (Fiber Bragg Grating) sensors. Currently there is no method available for testing the functionality and robustness of the system without setting up an actual sensor-network implying numerous FBG sensors in which each has to be heated/cooled individually.

As a verification method of the mentioned system, FBG reflection based scanning laser interrogator, an FBG-emulator is implemented to emulate the necessary FBG-sensors. It is capable of immediate emulation of any given FBG spectrum, thus any temperature. The concept provides advantages like, emulating different kinds of FBGs with any peak shape, variable Bragg-wavelength λB, maximal-reflectivity Rmax, spectral-width and degradation characteristics. Further it facilitates an efficient evaluation of different interrogator peak-finding algorithms and the capability of emulating up to 10000 sample points per second is achieved.

In the present paper different concepts will be discussed and evaluated yielding to the implementation of a Variable Optical Attenuator (VOA) as the major actuator of the emulator. The actuator choice is further restricted since the emulator has to work with light in unknown polarization state. In order to implement a fast opto-ceramic VOA, issues like temperature dependencies, up to 200V driving input and capacitive load have to be overcome. Furthermore, a self-calibration procedure mitigates problems like attenuation losses and long-term drift. Finally, measurement results of the combined interrogation module and the FBG ?emulator are presented.

9098-13, Session 3

High signal to noise acoustic sensor using phase shift gratings interrogated by the Pound Drever Hall technique

Peter Kung, QPS Photronics Inc. (Canada); Maria Cominici, McGill Univ. (Canada)

Optical fiber is made of glass, an insulator, and thus it is immune to strong electromagnetic interference. Therefore, fiber optics is a technology ideally suitable for sensing of partial discharge (PD) in both transformers and generators. Extensive development efforts have been used to find a cost effective solution for detecting partial discharge, which generates acoustic emission, with signals ranging from 30 kHz to 200 kHz. The requirement is similar to fiber optics Hydro Phone, but requires higher frequencies. There are several keys to success: there must be at least 60 dB signal-to-noise ratio (SNR) performance, which will ensure not only PD detection but later on provide diagnostics and also the ability to locate the origin of the events. Defects that are stationary would gradually degrade the insulation and result in total breakdown. Transformers currently need urgent attention: most of them are oil filled and are at least 30 to 50 years old, close to the end of life. In this context, an issue to be addressed is the safety of the personnel working close to the assets and collateral damage that could be caused by a tank explosion (with fire spilling over the whole facility). This paper will describe the latest achievement in fiber optics PD sensor technology: the use of phase shifted fiber gratings with a very high speed interrogation method that uses the Pound-Drever-Hall technique. More importantly, this is based on a technology that could be automated, easy to install, and, eventually, available at affordable prices

9098-14, Session 3

Study of interlaminar strain transfer of advanced composites by fiber Bragg gratings

Ataman Deniz, Esat S. Kocaman, Mehmet Yıldız, Sabanci Univ. (Turkey)

Due to nature of optical fiber, Fiber Bragg Grating (FBG) sensing systems have many advantages in monitoring composite structures compared to conventional strain sensing systems. One of the key advantages is that array of FBGs can be embedded into a laminated composite without endangering the integrity of the local structure. Unlike patch sensors, embedded FBGs show modified spectral response depending on the local structure of host media. Moreover when non-uniform strain distributions exits in the local structure surrounding the FBG, spectral response of the FBG may show signal anomalies which in turn affect peak and full width half maximum (FWHM) tracking.

Although FBG embedded in unidirectional laminated composites under bending or tensile loading configurations exhibit linear and predictable spectral responses there exists limited data on FBG spectral behavior of unidirectional interply hybrid composites. In this work spectral response of FBGs embedded in various unidirectional hybrid thin composites will be examined under tensile and bending loading configurations. A theoretical model will be derived from spectral responses of FBGs embedded in parent composites which will be later used in prediction/understanding of FBG response of hybrid laminated composites made of parent composites. The importance of hybrid composites is that nowadays variety of load bearing materials are being used to create more advanced structures. Therefore it is important to understand spectral behavior of FBG embedded in hybrid composites.

9098-15, Session 4

Using a multimode fiber as a high-resolution low-loss spectrometer *(Invited Paper)*

Brandon Redding, Hui Cao, Yale Univ. (United States)

The development of optical fibers has revolutionized telecommunications by enabling long-distance broad-band transmission with minimal loss. In turn, the ubiquity of high-quality low-cost fibers enabled a number of additional applications, including fiber sensors, fiber lasers, and imaging fiber bundles. In this work, we show that a multimode optical fiber can also function as a spectrometer by measuring the wavelength-dependent speckle pattern formed by interference between the guided modes. In practice, the wavelength-dependent speckle patterns are recorded in a transmission matrix. After calibration an arbitrary input spectra can be reconstructed based on the speckle pattern it produces. The spectral resolution is dictated by the change in wavelength required to produce an uncorrelated speckle pattern, which scales inversely with the length of the fiber. Using a 100 meter long multimode fiber, we were able to resolve two lines separated by merely 1 pm at a wavelength of 1500 nm. Broad-band operation is also possible by using a shorter fiber with lower resolution. We showed that a 4 cm fiber can provide 350 nm of bandwidth across the visible spectrum with 1 nm resolution. The fiber spectrometer consists only of a multimode fiber and a monochrome camera used to record the speckle patterns. Since the fiber can be coiled into a small volume, the entire spectrometer can be compact, lightweight, and low cost while providing ultrahigh resolution, broad bandwidth, and low loss.

9098-16, Session 4

Optical carrier based microwave interferometers for sensing application

Jie Huang, Xinwei Lan, Hanzheng Wang, Hai Xiao, Lei Yuan, Clemson Univ. (United States)

In an effort to bring together the strengths from both microwave and optics, a research area known as the microwave-photonics has been explored over the past 30 years. The combination of microwave and optics has indeed found many unique applications in optical communication, broadband wireless access network, radar and satellite instrumentation. Some successful examples include high-quality microwave sources, high-performance analog links, phased array antennas, frequency-tunable high-Q microwave filters and high-speed analog-to-digital convertors.

The success of microwave-photonics in telecommunications intrigued us to explore the possibility of combining microwave and optics for sensing applications. Here we describe the concept and implementation of a new optical carrier-based microwave interferometer (OCMI) for sensing application. The idea is to send the microwave-modulated optical signals through an optical interferometer and read the microwave signals only. High quality interference signal can thus be observed in the microwave domain by properly controlling the coherence length of optical and microwave source. The OCMI concept can be implemented on all types of optical interferometers such as Fabry-Perot, Fizeau, Michelson, Mach-Zehnder and Sagnac. OCMI has many unique features that the conventional optical interferometry does not have. For example, it can be applied to different types of optical fibers including multimode fibers, polymer fibers, photonics crystal fibers, and signal crystal sapphire fibers.

9098-17, Session 4

Optical vibration sensor based on Michelson interferometer arrangement with polarization-maintaining fibers

Jakub Cubik, Stanislav Kepak, Andrej Liner, Martin Papes, Tomas Kajnar, Ondrej Zboril, Vladimír Vašinek, VšB-Technical Univ. of Ostrava (Czech Republic)

Today, the interferometric sensors belong to the one of the most accurate, thanks to its great sensitivity. With their help we are able to measure temperature, strain, level, flow, vibration, stress, etc. For its operation the Michelson interferometer consist of the two arms terminated by mirrors, by which is possible to measure generated phase shift in the individual arms. Furthermore, were used polarization maintaining fibers. With this setup we will examine the effects of vibration and also how is this sensor influenced by the different setup arrangement and how it will manifest its frequency response. It is important to isolate the reference arm to increase the sensitivity of the measurement and the subsequent effect on the maximum phase shift and maxium frequencies response. In this work, we should describe various combinations of the arrangement of the measuring and reference arm and their effect on the sensitivity of different measured phenomena. Subsequently obtained frequency bands are evaluated for these various configurations and materials.

9098-18, Session 4

Fast-light enhanced fiber sensing: experiments, modeling, and practical design

Caleb A. Christensen, Anton Zavriyev, MagiQ Technologies, Inc. (United States)

It has been proposed that fast-light optical phenomena can increase the sensitivity of a Ring Laser Gyroscope (RLG) of a given size by several orders of magnitude. MagiQ Technologies is developing a compact fully-fibered fast light RLG using Stimulated Brillouin Scattering (SBS) in optical fibers with commercially mature technologies. We will discuss recent experimental results and numerical modeling related to fast light generation and implications for RLGs. We will present design considerations and performance estimates for an RLG. By using photonic integrated circuits and telecom-grade components along with specialty fibers, we believe that our design is appropriate for mass production without further advances in components. We avoid free-space optical elements (such as atomic vapor cells), in order to enable a compact, high sensitivity RLG stable against environmental disturbances. Results of this effort will have benefits in existing applications of RLGs (such as inertial navigation units, gyrocompasses, and stabilization techniques), and will allow wider use of RLGs in spacecraft, unmanned aerial vehicles or sensors, where the current size and weight of optical gyros are prohibitive.

9098-19, Session 4

Random drift modelling and noise compensation algorithm for fiber optic gyroscope signal

Mundla M. Narasimhappa, Samrat L. Sabat, Univ. of Hyderabad (India); Jagannath Nayak, Research Ctr. Imarat (India)

The interferometric fiber optic gyroscope (IFOG) is a core component in strapdown inertial navigation system (SINS) for measuring the angular rate of an object. IFOGs have been used for military and defense applications, due to its significant advantages such as small size, low cost, light weight, no moving parts, large dynamic range, low power consumption, possible batch fabrication. The performance of SINS has been degrades due to the uncertainty and IFOG errors of measurement. The output of IFOG is suffers with random noise and drift error, which are affected by the environmental effects (like temperature, pressure and so on) and sensor itself. In this paper, the IFOG random drift modeling and noise compensation techniques are addressed. The adaptive Unscented Kalman filter (AUKF) algorithm is proposed for denoised the IFOG signal. In this approach, the adaptive estimation of process, measurement noise covariance matrix is estimated based on innovation sequence. The proposed algorithm is applied for denoising IFOG signal under static and dynamic environment. Allan variance is a time domain technique used to analyze and quantify the noise characteristics of FOG sensor. Variance and standard deviation are the performance indicators of the proposed algorithm is static condition. The proposed algorithm is also tested for rate 10 deg/hr of raw FOG signal. In dynamic condition, the mean squared error (MSE) value is evaluated, which is a carry out indicator of adaptive approach after denoising.

9098-20, Session 4

A novel adaptive mechanism for improving the accuracy of fiber optic gyroscope

Mundla M. Narasimhappa, Samrat L. Sabat, Univ. of Hyderabad (India); Jagannath Nayak, Research Ctr. Imarat (India)

The interferometric fiber optic gyroscope (IFOG) is a core component in strapdown inertial navigation system (SINS) for measuring the angular rate of an object. IFOGs have been used for military and defense applications, due to its significant advantages such as small size, low cost, light weight, no moving parts, large dynamic range, low power consumption, possible batch fabrication. The performance of SINS has been degrades due to the uncertainty and IFOG errors of measurement. The output of IFOG is suffers with random noise and drift error, which are affected by the environmental effects (like temperature, pressure and so on) and sensor itself. In this paper, the IFOG random drift modeling and noise compensation techniques are addressed. The adaptive Unscented Kalman filter (AUKF) algorithm is proposed for denoised the IFOG signal. In this approach, the adaptive estimation of process, measurement noise covariance matrix is estimated based on innovation sequence. The proposed algorithm is applied for denoising IFOG signal under static and dynamic environment. Allan variance is a time domain technique used to analyze and quantify the noise characteristics of FOG sensor. Variance and Standard deviation results reveal that the proposed algorithm is static condition. The proposed algorithm is also applied for rate 10 deg/hr of raw FOG signal. In dynamic condition, the mean squared error (MSE) value is evaluated, which is a performance indicator of proposed approach after denoising.

9098-21, Session 4

Highly sensitive and compact temperature sensor based on the multimode interference in a liquid-filled photonic crystal fiber

Wei Lin, Nankai Univ. (China); Yinping Miao, Tianjin Univ. of Technology (China); Hao Zhang, Binbin Song, Bo Liu, Donglin Yan, Yan-Ge Liu, Weiwei Liu, Shengjiang Chang, Nankai Univ. (China)

Recently, the fiber optic interferometric sensors are extensively investigated owing to their outstanding advantages, such as portability, compactness, high geometric adaptability, anti-electromagnetic interference and resistance to high pressure and corrosion. The fiber interferometer can be classified into three types: Fabry-Pérotcavity, Sagnac loop and in-line modal interference. Among the in-line modal interferometer, the multimode interferometric sensors have attracted a growing interest in recent years, owing to their capability of simultaneous multi-parameter measurement. However, the applications of the multimode interferometric sensors are limited owing to the low sensitivity because the propagation constant differences of the eigenmodes are hard to be influenced by the variation of the surroundings, especially the temperature. To enhance the temperature sensitivity, the photonic crystal fiber is introduced to fabricate the interferometer, because of its capability of infiltrating the material to tuning the average refractive index of the cladding. And it's successful in the enhancements of the sensitivity in the sensors based on sagnac loop and Mach-Zehnder interferometer (a kind of in-line modal interference). However, few works are focused on the liquid-filled-PCF-based multimode interferometer.

In this work, a highly sensitive and compact temperature sensor is proposed based on the multimode interference in a liquid-filled photonic crystal fiber. This sensor is fabricated by fully infiltrating the photonic crystal fiber with a liquid which has the refractive index around the silica and splicing it between the single mode fibers. A high sensitivity of 6.74nm/°C is achieved. The proposed sensor would have potential application in multi-parameters sensing area.

9098-40, Session Posters-Thursday

Study on pattern recognition technology based on fiber perimeter security system

Haiyan Xu, Hohai Univ. (China)

Fiber perimeter security system is a kind of sensor system which uses optical fiber as the sensing media.Based on describing the principle of fiber perimeter security system, in order to recognize vibration signal from dual Sagnac fiber-optic sensor,a pattern recognition method based on endpoint detection technologies and wavelet energy entropy is introduced. In the experiment system, the power of the light source of 220uW, which working at a wavelength of 1 550 nm and the optical fiber length is 30 km .The experimental results show that the method we proposed can effectively distinguish the intrusion signal , environment noise and human activities caused by non-invasion, it can improve the recognition accuracy and reduce the false alarm rate?

9098-41, Session Posters-Thursday

Measurement of the microwave emitter's inhomogeneity using optical fiber DTS

Jakub Jaros, Andrej Liner, Martin Papes, V?B-Technical Univ. of Ostrava (Czech Republic); Pavel Smira, Andrea Nasswettrova, Thermo Sanace s.r.o. (Czech Republic); Vladimír Va?inek, Jakub Cubik, V?B-Technical Univ. of Ostrava (Czech Republic)

Researcher's teams were dealing with the microwave emitter's inhomogeneity problem since the microwaves were used. One possible way, how to measure electromagnetic field is the measurement of the temperature distribution on the irradiated subject. Inhomogeneous electromagnetic field causes on inhomogeneous temperature distribution on the irradiated sample, which can cause problems as in other material processing, so in the undesirable change of properties and even security. Inhomogeneity of electromagnetic field is specific by creating spots with higher or lower temperature called "hot spots". This inhomogeneity strongly affects the temperature distribution in the cross section of the material and its resultant heating. Given the impossibility of using classical electronic devices with metal temperature sensors were various indirect methods used in the past. This paper deals with experimental measurement of the microwave emitter's inhomogeneity (2.45~GHz) using the optical fiber DTS. The greatest advantage of this sensor system is just in using of the optical fiber (electromagnetic resistance, small size, safety using in inflammable and explosive area, easy installation). Due to these properties of the optical fiber sensor it's possible to measure the temperature of the sample in real time. These sensor are able to measure the temperature along the fiber, in some cases they use nonlinear effect in optical fiber (Raman nonlinear effect). The verification of non-homogeneity consists in experimental measuring of the temperature distribution within the wooden sample. The method is based on heat exchange in an isolated system where wooden sample serves as an absorber of the irradiated energy. To identify locations with different power density was used DTS system, based on nonlinear phenomena in optical fibers.

9098-42, Session Posters-Thursday

Laser line wavelength sensor by strain and temperature variations based in a dual-wavelength fiber laser with a Hi-Bi loop Sagnac interferometer

Manuel Durán-Sánchez, Ricardo I. Álvarez-Tamayo, Univ. Tecnológica de Puebla (Mexico); Olivier J. M. Pottiez, Ctr. de Investigaciones en Óptica, A.C. (Mexico); Evgeny A. Kuzin, Baldemar Ibarra-Escamilla, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico); Antonio Barcelata-Pinzón, Univ. Tecnológica de Puebla (Mexico)

A laser line wavelength by strain and temperature variations sensor based in an Erbium doped dual wavelength fiber laser is presented. The all-fiber linear laser cavity is based on a pair of fiber Bragg gratings (FBG) and a Hi-Bi fiber optical loop mirror (Hi-Bi FOLM). The Hi-Bi FOLM acts as a wide band optical mirror with a periodical transmission spectrum. The FBGs are used as strain and temperature sensors modifying the laser wavelength and the cavity loss adjustment to obtain single and dual wavelength operation. It is possible to estimate the temperature/strain variations at the FBG by the measuring of the optical power at the laser cavity output through a Hi-Bi FOLM fiber loop temperature scanning that allow to obtain the laser emission wavelength.

9098-43, Session Posters-Thursday

Fiber laser strain sensor based in the measurement of Sagnac interferometer optical power spectrum

Ricardo I. Álvarez-Tamayo, Manuel Durán-Sánchez, Univ. Tecnológica de Puebla (Mexico); Olivier J. M. Pottiez, Ctr. de Investigaciones en Óptica, A.C. (Mexico); Evgeny A. Kuzin, Baldemar Ibarra-Escamilla, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico); Antonio Barcelata-Pinzón, Univ. Tecnológica de Puebla (Mexico)

We report a fiber laser sensor based in a fiber Sagnac interferometer and a fiber Bragg grating (FBG). The linear laser cavity is formed with a Hi-Bi loop Sagnac interferometer in one side and a FBG in the other side. The FBG is used as a strain sensor within the laser cavity. The measurement of the Sagnac interferometer periodical spectrum optical power by temperature scanning in the Hi-Bi fiber loop is used to determine the laser line modified by strain applied on the FBG. This technique can be useful to obtain the laser line wavelength without expensive equipment due to the simple use of a power meter and a temperature measurement system.

9098-44, Session Posters-Thursday

Research on structural health monitoring of wind turbine blade by FBG sensors and Lamb wave

Yongkai Zhu, Nanjing Univ. of Aeronautics and Astronautics (China)

Structual health monitoring of wind turbine blade is a key technology issue in equipment testing. Among the emerging new testing methods, Lamb-wave based non-destructive testing is getting more and more attention. This paper proposes a method to acquire the Lamb-wave signal in wind turbine blade based on FBG sensors. Methods to acquire Lamb-wave in wind turbine blade using FBG technology were analyzed. The testing system of wind turbine blade was set up, to acquire weak signal from the surface of turbine blade. The technology of fast, large-area testing was proposed, to achieve precise location and complete destructive data acquisition. The testing of turbine blade with features of high-precision and high signal-noise-ratio was realized, which is meaningful to dynamic testing of large-scale and complex rotating structure.

9098-46, Session Posters-Thursday

Smartfiber: a strongly miniaturized embedded interrogator for a FBG sensor network in composite materials

Andrea Trita, Univ. Ghent (Belgium); Tahira Ahmed, Airborn Technology Ctr. B.V. (Netherlands); Geert Luyckx, Univ. Gent (Belgium); Eli Voet, FBGS Technologies GmbH (Germany); Garrie Vickers, Optocap Ltd. (United Kingdom); Iker Mayordomo, Fraunhofer-Institut für Integrierte Schaltungen (Germany); Dries Van Thourhout, Univ. Gent (Belgium); Jan P. Vermeiren, Xenics NV (Belgium)

In the framework of the FP-7 program SMARTFIBER, a novel, very compact interrogator for Fiber Bragg Grating (FBG) sensors is designed and demonstrated based on an optimized Arrayed Waveguide Grating (AWG) filter with 128 channels

The AWG response is tailored such to achieve large cross-talk between the output channels, which allows simultaneous detection of multiple FBG peaks, using centroid signal processing techniques, without constraints on the minimum FBG peak spectral width.

The measured interrogator resolution is 2.5 pm and the total measurement range is 50nm. The device is fabricated in Silicon on Insulator (SOI) platform, and has a footprint of only 2.2 x 1.5 mm. The integration with 128 pixel InGaAs array is made by Au stud flip-chip bonding.

The spectrometer signals are further integrated and processed in a Readout circuit (ROIC) based on an integrating transimpedance amplifer. The external electronics are based on a small footprint CPLD for the ROIC sequence, ADC operation and temperature control of the PIC and SLED. the wireless part is controlled with a microcontroller taking care about the wireless communication and the wireless power management. The complete embedded unit, including temperature controlled SLED, circulator and all fiber optic splices, is realised in 100 mm diameter 7 mm thick premold, which can be embedded together with the fiber chain.

9098-22, Session 5

Lab-on-fiber optofluidic platform for in-situ monitoring of drug release from therapeutic-eluting polyelectrolyte films *(Invited Paper)*

Fei Tian, Stevens Institute of Technology (United States); Jouha Min, Massachusetts Institute of Technology (United States); Jiri Kanka, Institute of Photonics and Electronics of the ASCR, v.v.i. (Czech Republic); Xiangzhi Li, Stevens Institute of Technology (United States); Paula T. Hammond, Massachusetts Institute of Technology (United States); Henry H. Du, Stevens Institute of Technology (United States)

Therapeutic-eluting polyelectrolyte polymer films deposited on implantable medical devices and components via layer-by-layer (LbL) assembly for controlled release as part of the patient-care strategy are at the frontier of the ever-expanding field of LbL research. Efficiency of this treatment strategy requires therapeutic release with dose profiles tailored to specific needs. This invited talk focuses on our recent work on the design and development of a lab-on-fiber optofluidic platform for in-situ and time-resolved measurements of the release profiles of a model drug-eluting system, [Poly/PAA/GS/PAA]n, under physiologically relevant conditions. At the core of the optofluidic platform is a long-period grating (LPG) structure inscribed in conventional single mode optical fiber housed in a capillary tube to mimic physiologically relevant fluid flow in a microenvironment.

The resonance wavelength of the higher order cladding mode of the LPG is highly sensitive to molecular absorption/desorption events during LbL deposition/dissolution, making it especially suitable as both a substrate and an in-situ sensor for LbL growth of the drug-eluting [Poly/PAA/GS/PAA] n and subsequent drug release. We show that the lab-on-fiber optofluidic platform is robust and yields critical release information not readily available using static flow condition in a macro release medium. Such information is of vital importance in the development and clinical insertion of therapeutic-eluting polyelectrolyte films for patient care.

9098-23, Session 5

Novel diaphragm micro fabrication techniques for high-sensitivity biomedical fiber optic Fabry-Perot interferometric sensors

Sven Poeggel, Daniele Tosi, Dinesh Babu Duraibabu, James Kelly, Maria Munroe, Gabriel Leen, Elfed Lewis, Univ. of Limerick (Ireland)

Extrinsic Fabry Perot Interferometer (EFPI) based optical fibre sensors can be utilised in in-vivo medical applications which require pressure detection, e.g.: cardiovascular diagnostics; intra-cranial pressure detection; and robotic surgery. In general, for such applications, the EFPI must have a high accuracy (1mmHg), be stable over time, and measure pressures in the range of approximately 0-180mmHg. Here we discuss recent experience relating to the development and fabrication of an all-glass biocompatible fibre optic based EFPI pressure sensor. The sensor is 200um in diameter and fabricated using only fibre splicing and a process to etch the EFPI diaphragm.

The pressure sensitivity of the EFPI is inversely proportional to the third power of the diaphragm thickness; hence, high sensitivity (1-5nm/kPa) can only be achieved by having a correspondingly low diaphragm thickness. In order to help accomplish this, a real-time method has been developed to monitor the diaphragm thickness during the etching process. Three different etching techniques have been investigated: 1) polishing; 2) Hydrofluoric (HF) acid; and 3) Focused Ion Beam milling (FIB).

By monitoring the diaphragm thickness during the etching process, it is possible to achieve a diaphragm thickness of 2-3um, and produce sensors with a 0.1mmHg resolution and <1 mmHg/hr drift rate. Here the on-line monitoring method is reported upon and the three etching techniques are compared in terms of stability, repeatability and efficiency. The sensors have been tested in air and several liquids, ensuring high stability, and resilience to impurities. Furthermore, a test in a cardiovascular simulator was successfully undertaken.

9098-24, Session 5

Fiber loop ringdown glucose sensors: sensing human diabetic urines

Malik Kaya, Chuji Wang, Mississippi State Univ. (United States)

Fiber loop ringdown technique has shown promise in biomedical applications in recent studies. In the present work, fiber loop ringdown sensors using the evanescent field as the sensing mechanism have been fabricated and tested in actual human urines for the first time. In order to evaluate the sensors' performance, the sensors were comparatively tested in healthy human urines, synthetic urine solutions, and diabetic urines. Due to different features or chemical compositions of each urine sample, the sensors experience different optical losses, equivalently, different ringdown times. The comparative results show that evanescent field-fiber loop ringdown glucose sensors can discriminate the three different urine samples by displaying different ringdown times. The evanescent field-fiber loop ringdown glucose sensors had fast response, good reproducibility, and high sensitivity. The promising results imply that the evanescent field-fiber loop ringdown sensors have potential for near real-time detection of diabetic urines.

9098-25, Session 5

Fiber optic SERS diagnosis of kidney transplant acute rejection using urine

Jingmao Chi, Hui Chen, Peter Tolias, Henry H. Du, Stevens Institute of Technology (United States)

Clinically, renal biopsy is the 'gold standard' to distinguish the acute rejection (AC) of renal allograft. It is an invasive procedure, however, with a substantial risk of complications and contraindications. In this study, we aim to establish a noninvasive, reliable, early diagnosis of renal acute rejection by evaluating urinary biomarkers using fiber-optic based surface-enhanced Raman scattering (SERS). Unclad sapphire fiber, which has low Raman background and high biocompatibility, immobilized with colloidal Ag nanoparticles was used as sensing probe for SERS measurements on untreated urine samples. Urine samples were collected from 56 kidney transplant patients at 6 time points at Newark Beth Israel Medical Center (NBIMC) in New Jersey. 3 AC episodes were diagnosed in 16 biopsies. By analyzing urine samples taken 1 day after kidney transplant surgery, we discover that 14 (including all 3 AC episodes) out of 16 SERS spectra of biopsies show similar spectral features that are highly distinct from patients without rejection. Based on the unique SERS bands, we propose that heme could be the major urinary biomarker attributable to the specific SERS features of biopsies. MALDI-TOF mass spectroscopy was employed to identify the urinary biomarkers.

9098-26, Session 5

Understanding the role of hemoglobin in altering multilayered tissue intrinsic fluorescence in the visible region using fiber optics

Bala K. Nivetha, Narayanan U. Sujatha, Indian Institute of Technology Madras (India)

Extraction of intrinsic fluorescence in a solid turbid medium such as tissue is a challenging problem due to the various interrelationships between different constituents of tissue. Alterations in fluorescence intensity occur during the transformation of tissue from normal to malignant. If the fluorescence happens to be in the visible region, predominant absorption of hemoglobin can quench the emission making the intrinsic extraction and hence the actual measurement of the respective fluorophore concentration erroneous. This work explores to understand the effect of hemoglobin quenching on emitted fluorescence of FAD (Flavin Adinine Dinucleotide) in layered skin tissue phantoms. The alteration in the concentration of tissue FAD is a characteristic of tissue malignancy. Monte Carlo simulations on layered phantoms were performed with varying concentrations of FAD and hemoglobin and the results are correlated with fluorescence measurements obtained using a fiber optic probe based spectroscopic setup. The results obtained are expected to open up ways of compensating the loss of FAD emission due to the hemoglobin absorption to facilitate the determination of true FAD content in the tissue and thus help in grading the level of tissue malignancy.

9098-27, Session 6

Exploration of higher-order mode coupling in long-period gratings for sensitive monitoring of polyelectrolyte self-assembly at the nanoscale

Fei Tian, Stevens Institute of Technology (United States); Jiri Kanka, Institute of Photonics and Electronics of the ASCR, v.v.i. (Czech Republic); Xiangzhi Li, Henry H. Du, Stevens Institute of Technology (United States)

Layer-by-layer (LbL) self-assembly via hydrogen bonding is one of the primary mechanisms to achieve stimuli-responsive polyelectrolyte thin films for a variety of applications. The ability to monitor the individual LbL steps in situ is of great significance in the development and understanding of hydrogen-bonded LbL systems of new design functions and properties. Long-period gratings in single-mode fiber (SMF-LPG) has the potential for such application by virtue of its high index sensitivity. We report a theoretical and experimental investigation to sort out the coupled cladding mode that is most sensitive to molecular adsorption events during LbL deposition. We demonstrate via numerical simulation and experiments that higher order cladding modes in SMF-LPG have two orders of magnitude advantage over their lower order counterparts in resonance wavelength response. The sensitivity of SMF-LPG to LbL deposition can be further improved at turning around point in the phase matching curve of the LPG structure, according to our simulation.

9098-28, Session 6

Fiber pigtailed thin wall capillary coupler for excitation of microsphere WGM resonator in chemical/thermal sensing

Hanzheng Wang, Xinwei Lan, Jie Huang, Lei Yuan, Hai Xiao, Clemson Univ. (United States)

Optical microresonators have been proven as an effective means for sensitive chemical and thermal sensors development. The changes in refractive index near the resonator surface and the thermal optic effect on the resonator lead to the effective refractive index change and thus a shift at certain resonance wavelength. The high quality (Q) whispering gallery modes (WGMs) contributed by the rotationally symmetric structures will interact with the local circumstances through the evanescent field. The high sensitivity in detection was achieved by the long photon lifetime of the high-Q resonator (thus the long light-environment interaction path).

In this paper, we present our recent research on using fiber pigtailed capillary coupler for WGM resonator excitation and its sensing applications. Capillary tube with wall thickness of several microns was used as the waveguide. The PMMA microsphere and porous glass microsphere (PGM) were integrated with the etched capillary tube for different sensing purposes. The Q-factors and free spectrum ranges (FSR) of different types of microspheres were measured by coupling light into the microsphere using novel fiber pigtailed capillary coupler. Chemical vapor at different concentrations were tested using PGM microresonator. Temperature sensing was tested based on PMMA microsphere resonator. This alignment free structure provides a new sensing probe based on WGM resonator concept.

9098-29, Session 6

Sapphire fiber sensor based on evanescent-field surface-enhanced Raman scattering

Hui Chen, Fei Tian, Jingmao Chi, Stevens Institute of Technology (United States); Jiri Kanka, Institute of Photonics and Electronics of the ASCR, v.v.i. (Czech Republic); Henry H. Du, Stevens Institute of Technology (United States)

Unclad sapphire optical fiber is inherently multi-mode, which requires the excitation of higher order modes with strong mode-field overlap for evanescent-field based sensing and measurements, particularly using surface-enhanced Raman scattering (SERS) as the sensing modality. We present a theoretical and experimental study that aims to realize evanescent-field SERS sensing utilizing sapphire fiber. Beam Propagation Method (BPM) was used to simulate excitation of high-order modes to enhance the evanescent overlap. Generalized Multi-particle Mie (GMM) solution was employed to analyze the interactions between Ag plasmonic nanoparticles and the higher-order modes for optimal Raman scattering and signal coupling. With simulation as a guide, we immobilized colloidal Ag nanoparticles on sapphire fiber along the fiber length at different coverage densities for SERS measurements of Rhodamine 6G (R6G) model analyte. We show that Raman intensity increases with the coverage density of Ag nanoparticles even in the high density region, contrary to reported studies using single-mode optical fiber based on silica. We demonstrate that a limit of detection as low as 10-9 M could be achieved for R6G in aqueous solutions. Due to the low Raman background of sapphire fiber, as opposed to silica fiber, its development as a robust SERS probe is expected to significantly extend the realm of fiber optic-based chemical sensing and detection.

9098-30, Session 6

Gas diffusion in micro-machined HC-PCF methane sensors

Mohammad Amanzadeh, Saiied M. Aminossadati, The Univ. of Queensland (Australia)

This paper reports on development of a potential ultra-fast response and distributed gas spectroscopy sensor heads for underground coal mining. Multiple micro-channels were machined in hollow-core photonic crystal fibres as gas sensor heads using focoused ion beam and laser milling. This enables the gas mixture to access the holly core for interaction with laser light. Gas diffusion to the holly core is modeled considering microscopy measurements of drilled holes. The optimal length of sensor head and drilling positions are accurately calculated to achieve required sensing accuracy and response time. Engineering design of sensor heads was highlighted.

9098-31, Session 6

Multimaterial fibers: a new concept in infrared fiber optics

Guangming Tao, Ayman F. Abouraddy, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Rapid progress in quantum cascade lasers (QCLs) that span mid-wave and long-wave infrared wavelengths necessitate developing new infrared fibers capable of transmitting light in the 5?12 micron range. The most suitable material for IR fiber that could cover this range is glassy tellurium-based chalcogenide glass. We produce a novel infrared optical fiber with tellurium-based chalcogenide core and cladding, provided with a built-in polymer jacket by multimaterial coextrusion. We characterize the optical performance of the fiber in the 5 - 12 micron spectral window and demonstrate the mechanical robustness of the fiber.

9098-32, Session 7

A multicore optical fiber for distributed sensing *(Invited Paper)*

Xiaoguang Sun, Jie Li, David T. Burgess, Mike Hines, OFS (United States)

We deigned and manufactured a multicore optical fiber with three graded index (GI) multimode(MM) and one single mode (SM) cores. The GI cores have diameter of 50um and numerical aperture of 0.2 to be compatible with existing MM fiber in distributed Raman sensing. The SM fiber has a cutoff of 1280nm and a mode field diameter of 10um at 1550nm, which can be used for distributed Brillouin sensing. The fiber was coated with Silicone coating and ETFE buffer for high temperature applications. The fiber properties such as geometry, crosstalk and attenuation etc. are described. Method for coupling the signal from the individual cores to separate optical fiber is also presented.

9098-33, Session 7

Analysis of the suitability of fiber optic cables for illicit connections localization within sewers using the fiber optic distributed temperature sensing

Martin Papes, Petr Koudelka, Andrej Liner, Petr Siska, Jakub Jaros, Stanislav Kepak, Vladimír Va?inek, V?B-Technical Univ. of Ostrava (Czech Republic)

At present, most of the populated areas are equipped with sewer network. It is a complex system, which is usually very complicated and therefore it's very difficult to control and maintain. Nowadays, one of the biggest problems of sewers are illicit connections. Waste water is discharged by illegal connections into the sewer system that is not designed for this type of polluted water. This leads not only to aesthetic problems of surface water, but also to dangerous environment pollution. Due to these reasons are sewer companies trying to seek these illegal connections to prevent environmental pollution and burdening of waste water treatment plants with large amount of water. Various methods are used for searching these connections such as camera system/robot, paint test, smoke test, visual surveys or hydrochemical surveys. New approach in this area is the utilization of fiber-optic distributed sensing method using an optical fiber as a sensor. This method uses nonlinear Raman Effect in optical fibers and the measurements can be implemented to real time. Because of these advantageous properties of optical fibers, which are for example electromagnetic resistance, small size, easy installation and in this case mainly low cost, are mentioned sensory systems beginning to deploy in the industrial environments. The aim of this paper is to analyze the suitability of fiber-optic cables for localization of illicit connections within sewers using the fiber-optic distributed temperature sensing in terms of sensibility and mechanical resistance of the fiber-optic cables.

9098-34, Session 7

Balanced PIN-TIA photoreceiver with integrated 3 dB fiber coupler for distributed fiber optic sensors

Shubhashish Datta, Sruti Rajagopalan, Shaun Lemke, Abhay M. Joshi, Discovery Semiconductors, Inc. (United States)

Distributed fiber optic sensors based on optical scattering techniques have been used to monitor several physical parameters, namely pressure, temperature, and mechanical stress, in remote locations with occasionally harsh environments, such as oil and gas reservoirs, pipelines, dams, and power transmission lines, to name a few. Coherent optical detection is often employed to increase the sensitivity and dynamic range of these sensors. The performance of such systems hinges on that of the balanced optical detector used to detect the weak scattered signals. For example, the length resolution of the system improves with increasing detector bandwidth. Also, detection of Brillouin scattering in silica fibers requires optical detector with >11GHz bandwidth. The optical power handling of the detector determines the maximum local oscillator power, and therefore the coherent gain of the system. High common mode rejection ratio (CMRR) is needed to suppress the laser's relative intensity noise for shot noise limited operation.

We report a balanced PIN-TIA photoreceiver integrated with a 3dB fiber coupler for distributed fiber optic sensors. This detector demonstrates 3dB bandwidth >15GHz and coupled conversion gain >65V/W per photodiode through either input ports of the 3dB coupler, and can be operated at local oscillator power of +17dBm. The combined common mode rejection of the balanced photoreceiver and the integrated 3dB coupler is >20dB. We also present measurement results with various optical stimuli, namely impulses, sinusoids, and pseudo-random sequences, which are relevant for time domain reflectometry, frequency domain reflectometry, and code correlation sensors, respectively.

9098-35, Session 7

Fast variable optical attenuator based optical current transformer

Pu Wei, Xiaohan Sun, Southeast Univ. (China)

The optical current transformer (OCT) based on Faraday rotation have been presented for many year which encountered practical and economic challenges, due to the susceptibility of the polarization state of the light to temperature, vibration, external pressure, and material aging.

In this paper, we propose a novel hybrid optical current transformer (H-OCT), which is more practical to be widely used and simpler, compared with OCTs based on Faraday rotation. The conventional current sensing means such as low-power current transformer (LPCT) was utilized and optical fiber was employed as the transmission medium only. The fast variable optical attenuator (FVOA) is used to modulate the lightwave according to the voltage from the low-power current transformer (LPCT), which is proportional to the primary current.

The transfer function of the FVOA is experimentally estimated by the step response and an optic-electro feedback loop with the PID control algorithm is designed to compensate the nonlinearity of the transformer. The transformer is built with experimentally proved high linearity, the R-square value of which is equal to unity. The accuracy of the transformer is also test by a commercial calibrator. The results show that the ratio and phase errors were under 0.7% and 5 minutes which meet the IEC 0.1 class. In addition, the complexity and the cost are effectively reduced compared with other OCTs.

9098-36, Session 7

A fiber optic voltage sensor based on intensity modulation

Musa Ndiaye, Copperbelt Univ. (Zambia) and Northumbria Univ. (United Kingdom)

A fiber optic DC voltage sensor based on an intensity modulation scheme is proposed. Fiber optic voltage sensors have the advantage over conventional voltage sensors in that they offer voltage isolation and can easily be incorporated in telecommunication systems. The intensity modulation approach to sensing is a less costly and simpler measurement system compared to other available fiber optic voltage sensor techniques. Intensity modulation is achieved using a piezoelectric ceramic which produces a displacement on application of a voltage varying the transmitted optical power in a fiber to fiber coupling system.

A critical analysis was performed on the theory behind the intensity modulation scheme for fiber voltage sensing. Simulations and experimental investigations based on this concept showed good linearity between the applied voltage and optical power in the fiber. The feasibility of obtaining a single valued relationship for voltage sensing purposes was also observed.

The constructed voltage sensor produced useful results with the sensor exhibiting good linearity in forward and reverse voltages over a DC voltage of 0V to 100V but exhibited hysteresis. A linearity of 92% and 88.8% was measured for the forward and reverse voltages respectively and a dynamic range of approximately 0.3dB over the 100V range was achieved with a resolution of 1.9V. The hysteresis in the sensor was measured at 20%. Based on the results obtained recommendations have been made on a more linear, lower hysteresis and stable sensor of this type.

9098-37, Session 7

Intensity insensitive one-dimensional optical fiber tilt sensor

Badrinath Vadakkapattu Canthadai, Vidya Jyothi Institute of Technology (India); Dipankar Sengupta, Univ. degli Studi di Padova (Italy); Kishore Putha, National Institute of Technology, Warangal (India)

The paper presents a proximity sensor based on plastic optical fiber as tilt sensor. The sensor is insensitive to source fluctuation and can detect tilt angle up to 20deg and the achieved sensor sensitivity 0.256V/deg.

Introduction:In this paper a simple, low-cost and high-sensitivity fiber-optic tilt sensor based on the change in angle of the cantilever with respect to the fiber probe is presented and the sensor works on proximity sensor principle.

Principle of operation:

The basic principle of this fiber optic reflection sensor includes two multimode fibers with a step index profile, where one is transmitting fiber and the other is receiving fiber. The light is launched into the transmitting fiber and on emergence reflected by the reflector and is received by the receiving fiber. The light intensity is sensed by a photo-detector to be displayed as output power in volts. The incident light on the reflector forms a cone of emittance from transmitting fiber. It is reflected back in the form of expanding cone of light. The reflected light intensity collected by the receiving fiber depends on the separation between probe and reflector.

9098-38, Session 7

Development of a low cost tilt sensor using plastic optical fiber

Dipankar Sengupta, Univ. degli Studi di Padova (Italy); Badrinath Vadakkapattu Canthadai, Vidya Jyothi Institute of Technology (India); Kishore Putha, National Institute of Technology, Warangal (India)

In this paper we have presented the optical response of a fiber optic proximity sensor that measures the tilt angle of a cantilever due to the movement of a load attached to it at its edge. We have setup a simple reflection based sensor head made of two plastic optic fiber of diameter 980/1000 μm. A reflector is fixed on a cantilever and is mounted normal to the sensor head. Light from one of the two fibers is allowed to fall on the reflector and the reflected light from the reflector is collected by another fiber. The reflected light after passing through the fiber is measured by a photo diode through an transimpedance amplifier. A small amount of load is attached to the end of the cantilever in such a way that it can swing freely parallel to the horizontal axis of the cantilever only. The deflection of the cantilever depends on the angular displacement of the load from its normal position. The recorded change in intensity of light (in terms of voltage) due to angular displacement of the load is found linear. The experimental results show the sensitivity 0.256V/0 (degree) with respect to the angular displacement of the load. The experimental setup can be used for tilt measurement in civil engineering applications.

SPIE. DSS SENSING TECHNOLOGY+ APPLICATIONS

9099-1, Session 1

Underwater polarization camera for real-time and high definition imaging

Samuel B. Powell, Viktor Gruev, Washington Univ. in St. Louis (United States)

In this paper, we will describe our underwater polarimeter used for real-time imaging of marine phenomena. The polarization imaging sensor is based on a division of focal plane polarimeter and is implemented by integrating pixelated aluminum nanowire filters with an array of CCD imaging elements. The polarization imaging sensor is integrated with a PC104 computer using a gigabit Ethernet interface, allowing for 40 frames per second of HD format video. The underwater system allows for user control of focus, aperture, zoom, and integration time. Additionally, two integrated high definition monitors display various processed data to the user such as the Stokes parameters, degree of linear polarization, angle of polarization, and others. We will discuss our efforts in calibrating the polarimeter for underwater use and the algorithms for presenting calibrated data to the user in real-time. Detailed information on the quality of the calibration in terms of reconstruction accuracy will be presented as well. Finally, we will present field-test footage collected at the Lizard Island Research Station on the Great Barrier Reef.

9099-2, Session 1

Snap-shot imaging polarimeter: performance and applications

Neal Brock, Charles M. Crandall, James E. Millerd, 4D Technology Corp. (United States)

A camera capable of obtaining single snap-shot, quantitative, polarimetric measurements is investigated to determine its performance characteristics. The camera employs a micropolarizer array with linear wiregrid polarizers oriented at 0, 45, 90, and, 135 degrees. The wiregrid polarizers achieve an excellent spectral response from 300 - 3000nm which exceeds the 300 – 1000nm spectral response of the scientific CCD camera used. Cameras based on these micropolarizers have been built with individual polarizer elements as small as 7.4 microns and with full array sizes as large 4 Mega-pixels. The pixelated polarization camera acquires the four polarization orientations in a single video frame, which enables instantaneous measurements of the linear stokes parameters. The spatial resolution characteristics and limitations are discussed. Measurement guidelines are given to minimize the effects of noise sources such as pixel cross-talk, pixel uniformity, and camera noise. The benefit of these calibration methods as well as the benefit of averaging video frames on measurements such as Angle of Linear Polarization and Degree of Linear Polarization is demonstrated in a series of controlled experiments. A practical example of measuring stress induced birefringence is demonstrated.

9099-3, Session 1

Polarization in a snap: imaging polarimetry with microgrid polarizer arrays

Dmitry Vorobiev, Michael G. Gartley, Zoran Ninkov, Rochester Institute of Technology (United States)

Polarization, flux, and the spectral energy distribution of light are the fundamental parameters that we measure in order to infer properties of the sources of electromagnetic radiation, such as intensity, temperature, chemical composition and shape. Recently, the fabrication of microgrid polarizer arrays (MGPAs) facilitated the development of a new class of division-of-focal plane polarimeters. These devices have inherent capability to measure the degree and angle of polarization across a scene with a single exposure.

We present the design of the Rochester Institute of Technology Polarization Imaging Camera (RITPIC), a snapshot polarimeter for visible and near-infrared remote sensing applications. RITPIC is a compact, light-weight and mechanically robust imaging polarimeter that is deployable on terrestrial, naval, airborne and space-based platforms. RITPIC is developed using commercially available components and is capable of fast cadence imaging polarimetry of a wide variety of scenes. We derive the expected performance of RITPIC using the first high resolution 3D finite-difference time-domain (FDTD) models of these hybrid focal planes and simulated observations of synthetic scenes rendered with the Digital Imaging and Remote Sensing Image Generation (DIRSIG) model. Furthermore, we explore applications in remote sensing for which RITPIC, and devices like it, provide unique advantages.

9099-4, Session 1

GP-grid image interpolation and denoising for division of focal plane sensors

Elad Gilboa, Arye Nehorai, Washington Univ. in St. Louis (United States); John P. Cunningham, Columbia Univ. (United States); Viktor Gruev, Washington Univ. in St. Louis (United States)

Image interpolation and denoising are important techniques in image processing. These methods are inherent to digital image acquisition as most digital cameras are composed of a 2D grid of heterogeneous imaging sensors such as division of focal plane polarization sensors. Because each sensor only observes partial information, it is standard practice to interpolate missing components across the sensors, and the interpolation scheme has substantial bearing on image quality. Recently, there has been a growing interest in the use of Gaussian processes (GP) regression for interpolation and denoising of image data. However, exact GP regression suffers from O(N^3) runtime for data size N, making it intractable for image data (which is often in the millions for basic images).

Here we focus specifically on GP for division of focal plane sensors. Our GP-grid algorithm uses the multiplicative structure of most common kernels to reduce runtime complexity from O(N^3) to O(N^3/2). Importantly, our GP-grid algorithm is exact, requiring no approximations or sparsification procedures to perform inference. We then generalize GP-grid to handle incomplete grids and heteroscedastic noise, which importantly enables GP-grid to naturally incorporate known statistical properties of image capture. These advances lead to significant improvements over current methods in both interpolation and denoising. We provide a comprehensive mathematical model as well as experimental results of the GP interpolation performance for division of focal plane polarimeter. The GP interpolation accuracy of extracted polarization information outperforms previously published interpolation methods for polarimeters.

9099-5, Session 1

Hardware and demosaicing algorithms for improved microgrid polarimeters

Daniel A. LeMaster, Air Force Research Lab. (United States); Keigo Hirakawa, Univ. of Dayton (United States)

We recently proposed a new approach for microgrid polarimetric imaging with improved spatial resolution. Here, we expand this original work to include additional aspects of hardware design and demosiacking algorithms. Comparisons are made between conventional and improved microgrid imaging polarimeters using synthetic imagery.

9099-6, Session 2

Effects of wildfire smoke on atmospheric polarization

Joseph A. Shaw, Nathan J. Pust, Elizabeth Forbes, Montana State Univ. (United States)

An all-sky polarization imager is operated continuously at Montana State University in Bozeman, Montana. This system was used in August 2012, along with a suite of in-situ and remote aerosol sensors, to characterize the atmosphere before, during, and after the onset of a local wildfire. This provided a rare opportunity to observe the onset and temporal evolution of the smoke plume on skylight polarization. The spatially localized plume at first created a spatially asymmetric reduction of skylight polarization in the part of the sky nearest to the plume, and then evolved to provide a spatially uniform reduction of polarization when the plume filled the valley with smoke by the 2nd day. Detailed measurements of the changing aerosol properties will be shown and correlated with the changing polarization pattern.

9099-7, Session 2

Increasing range and minimizing polarization mixing with circularly polarized light through scattering environments

John D. van der Laan, College of Optical Sciences, The Univ. of Arizona (United States); David A. Scrymgeour, Shanalyn A. Kemme, Sandia National Labs. (United States); Eustace L. Dereniak, College of Optical Sciences, The Univ. of Arizona (United States)

We present both simulation and experimental results showing that circularly polarized light maintains its degree of polarization better than linearly polarized light. This is specifically true in turbid environments like fog and clouds, modeled here with polystyrene beads in water. In contrast to previous studies that propagate single wavelengths through broad particle-size distributions, this work identifies regions where circular polarization persists further than linear by systematically surveying different wavelengths through monodisperse particle diameters. In monodisperse polystyrene microspheres in water we show, for particle diameters of 1, 2, and 3 microns and varying optical depths, that circular polarization's ability to persist through multiple scattering events is enhanced by as much as a factor of four, when compared to that of linear polarization. These particle sizes correspond to size parameters found for infrared wavelengths and marine and continental fog particle distributions. To further demonstrate circular polarization's utility in realistic fog environments, laboratory-generated fog experiments are conducted and results are analyzed. The experimental results are compared to Monte Carlo simulations for all scattering environments investigated. Finally, we propose that polarization imaging techniques used to increase contrast and target discrimination can be successfully applied for a broader range of scattering environments, including fog and clouds.

9099-8, Session 2

An assessment of forward 1D vector radiative transfer modeling accuracy with aerosol remote sensing in mind

Anthony B. Davis, Olga V. Kalashnikova, David J. Diner, Michael J. Garay, California Institute of Technology (United States); Alexei I. Lyapustin, Sergey V. Korkin, NASA Goddard Space Flight Ctr. (United States); John V. Martonchik, Vijay Natraj, Suniti Sanghavi, Feng Xu, California Institute of Technology (United States); Pengwang Zhai, NASA Langley Research Ctr. (United States); Alexander A. Kokhanovsky, Univ. Bremen (Germany) and EUMETSAT (Germany)

Characterization of the omnipresent atmospheric aerosol is key to many applications of remote sensing. Beyond their obvious importance for climate and air quality applications, aerosols matter in defense and national security applications ranging from war fighter support to atmospheric corrections in hyper-spectral monitoring for nonproliferation treaty verification. In recent years, accurate observation of the state of polarization of photon fluxes at optical sensors in visible and near-IR spectrum has been pursued as a promising approach to aerosol remote sensing. Consequently, there has been a flurry of activity in polarized or "vector" radiative transfer (vRT) model development. This covers the multiple scattering and ground reflection contributions to sensor signals and complements single-particle scattering computation at the core of physics-based retrieval algorithms.

What level of model fidelity (representativeness of natural scenes) and numerical accuracy should be targeted in view of the practical constraints that apply? At a minimum, these constraints are: (1) desired accuracy for the retrieved aerosol properties, (2) observational uncertainties, and (3) operational efficiency requirements. We offer a rational and balanced approach to address this question, and illustrate it with an inter-comparison of a diverse set of 1D vRT models using a small but representative set of test cases. The benchmarking exercise splits naturally into two parts. First, emphasis is on stratified atmospheres with a continuously varying mixture of molecular and aerosol scattering and absorption over a black surface. Then emphasis shifts to the variety of surfaces, both polarizing and not, that can be encountered and may confuse the aerosol retrieval algorithm if not properly treated.

9099-9, Session 2

Atmospheric aerosol characterization through ground-based SPEX and iSPEX multi-angle spectropolarimetry

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We have designed, constructed, tested and calibrated several SPEX instruments: multi-angle spectropolarimeters for atmospheric aerosol measurements through the analysis of scattered sunlight. These instruments are based on the spectral modulation principle for linear polarization that yields accurate polarization measurements in one shot, without the use of any active optical components. We have carried out blue-sky measurements with the prototype SPEX satellite instrument and a dedicated SPEX instrument for implementation within a ground-based air quality measurement network. We present the data reduction and calibration of these measurements, and show how aerosol properties are retrieved from the continuum polarization, as well as from the polarization inside the O2A band, which can be separated/distinguished from the much broader spectral modulation.

We have also developed a smartphone version of SPEX: iSPEX, which is low-cost, mass-producible and yet relatively accurate owing to its spectral polarization modulation. We present first results from the iSPEX citizen science experiment to measure atmospheric aerosols with thousands of participants throughout The Netherlands.

9099-10, Session 3

An overview of polarimetric sensing techniques and technology within different research fields *(Invited Paper)*

Frans Snik, Leiden Univ. (Netherlands); Julia M. Craven-Jones, Sandia National Labs. (United States); Antonello De Martino, Ecole Polytechnique (France); Michael J. Escuti, North Carolina State Univ. (United States); Silvano Fineschi, INAF - Osservatorio Astronomico di Torino (Italy); David M. Harrington, Univ. of Hawai'i (United States); Dimitri P. Mawet, European Southern Observatory (Chile); Jérôme Riedi, Univ. des Sciences et Technologies de Lille (France); J. Scott Tyo, College of Optical Sciences, The Univ. of Arizona (United States)

We report the main conclusions from an interactive, multidisciplinary workshop on "polarimetric techniques and technologies", held on March 24-28 2014 at the Lorentz Center in Leiden, the Netherlands. The workshop brought together polarimetrists from different research fields: from astronomy to biomedical research, from atmospheric remote sensing to military target detection. Participants had backgrounds ranging from academia to industrial R&D.

Here we provide an overview of polarimetric instrumentation in the optical regime geared towards a wide range of applications. We identify common approaches and challenges. We list novel polarimetric techniques and polarization technologies that enable promising new solutions. We conclude with recommendations to the polarimetric community at large on joint efforts for exchanging expertise.

9099-11, Session 3

Activity-based intelligence tipping and cueing using polarimetric sensors

Christian Lewis, David Messinger, Michael G. Gartley, Rochester Institute of Technology (United States)

Activity-Based Intelligence (ABI) is a method of intelligence gathering whose primary concern are the actions and interactions of people within a given scene. Activities are determined by tracking the temporal movement of objects. Traditionally, movement is characterized by using a simply change detection scheme known as frame differencing. If all movement is correctly detected, then the inherent assumption is that everything that moved is equally notable. Everyday life would indicate that premise to be false. In order to assist in the detection process and identify interesting objects, we implemented a technique known as tipping and cueing. By using the polarimetric signature of an object to tip the polarimetric detection algorithms, an adjacent sensor can be cued to keep track of said object. We then monitor interactions between people in the scene and this object of interest. In this experiment we use multiple sensor platforms mounted on a roof, to observe a group of choreographed pedestrians below. A narrow field of view (NFOV) polarimetric sensor is used to cue a wide FOV (WFOV) Go-Pro 3. The polarimetric sensor uses a CCD camera in combination with a spinning filter wheel fitted with four polarimetric filters angled at 45 degree intervals from zero to 135. The narrow FOV is a consequence of the depth of the spinning filter wheel attachment. This limitation is address by focusing the sensor on a well-traversed intersection within the scene. The frame rate of this system is 6Hz, whereas the Go-Pro 3 operates a RGB camera at 60Hz. This difference in temporal fidelity requires that we evaluate each polarized frame both individually and in combination, or experience large temporal intervals with no polarimetric data. Individually, each frame will be reviewed for large contrast differences relative to the background. In combination, the degree of linear polarization (DOLP) will be used to further distinguish objects of interest. It is important to note, that the polarization data will only be used to indicate the existence of an object, not the lack thereof. Thus no objects will be removed if no signature is detected. Upon completion of the experiment, the resulting data will be used in a comparative analysis to determine whether polarimetric tipping and cueing improved the end-to-end process of activity recognition.

9099-12, Session 3

Preliminary measurements of the polarimetric signatures of human targets

Van A. Hodgkin, Dawne M. Deaver, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Daniel A. LeMaster, Air Force Research Lab. (United States)

The reflective bands in modern imaging, i.e., the visible through the short wave infrared (SWIR), have become very attractive for use in both daytime and low light target acquisition and surveillance. In addition, the nature of the target in modern conflict again includes the human body as a principle target. The spectral natures of the reflectivities of humans, their clothing, what they may be carrying, and the environments in which they are immersed, along with the spectral nature and strength of the light sources that illuminate them, have been the essential components of the signatures used in models that predict probabilities of target acquisition and discrimination. What has been missing from these sets of signature components is the impact these target and background materials have on the polarization of the light that is imaged. This paper documents a preliminary theoretical and experimental investigation into the active and passive polarimetric signatures of human targets carrying lethal and nonlethal objects in the SWIR.

9099-13, Session 3

A covariance-based anomaly detector for polarimetric remote sensing applications

Joao M. Romano, U.S. Army Armament Research, Development and Engineering Ctr. (United States); Dalton S. Rosario, U.S. Army Research Lab. (United States)

The proposed paper recommends a new anomaly detection algorithm for air-to-ground polarimetric remote sensing applications using a multi-polarimetric data cube as input. By stacking the independent measurements, I0 and I90, captured by a polarimetric camera, one can generate a multipolarimetric cube where the x and y axis represent the spatial information and the z-axis the polarimetric information. Using this new format, it will be shown that one can take advantage of some key features that lend themselves in discriminating manmade objects from natural clutter backgrounds more effectively than using the well known Stokes parameters. The paper demonstrates that variability is key in discriminating manmade objects from natural clutter when using this new multi-dimensional feature space which, as the paper will show, can be successfully exploited using the M-Box covariance test. The paper demonstrates: 1) how independent polarization measurements contains information suitable for manmade object discrimination by taking advantage of the variability difference between manmade objects and natural clutter; 2) a detailed analysis and comparison between the variability exhibited by manmade objects relative to natural clutter; 3) an in-depth comparison between the M-Box covariance test algorithm with Stokes parameters S0 and S1, DoLP, RX-Stokes, PCA RX-Stokes, and the LoGC, a previously proposed algorithm by the authors as a covariance discriminator; and finally 4) the data used for the comparison spans 3 days 24-hour measurements over a variety of weather conditions, target states, and diurnal cycle.

9099-15, Session 3

High-speed birefringence mapping by polarization camera and its application for film orientation tracking

Takashi Onuma, Yukitoshi Otani, Utsunomiya Univ. (Japan)

A polarization camera with a sampling speed of over 1 kHz at full resolution has been developed based on a CMOS sensor and a micropolarizer array made of a photonic crystal. A high-speed birefringence mapping is achieved by applying a phase-shifting method after illuminating circularly polarized light to a sample. In addition, it is applied for dynamic racking of optical film orientation to analyze the volume change. We succeed to determine real birefringence effect by compensating thickness change. The performance of the system is quantified by measuring the birefringence distribution in the optical film. The image connection and synchronization techniques are also proposed to record the birefringence of long optical films.

9099-16, Session 3

LWIR polarimetry for enhanced facial recognition in thermal imagery

Kristan P. Gurton, Alex J. Yuffa, U.S. Army Research Lab. (United States)

We report results and analysis for a series of LWIR polarimetric images of facial profiles in which identifiable features are greatly enhanced when compared to conventional LWIR imagery. It was generally thought that conventional thermal imagery (MidIR or LWIR) was ineffective for reliable identification of particular individuals because of its inability to resolve detailed facial features due to the so-called "ghosting-effect". By utilizing additional polarimetric information of the image forming radiance we are able to extract subtle surface features of the face, thus improving subject identification. Polarimetric image sets considered include the conventional intensity thermal image, S0, the two Stokes images, S1 and S2, and various Stokes image products, e.g., degree-of-linear-polarization (DoLP), and the orientation image (ORT). Finally, Stokes imagery is combined with Fresnel relations to extract additional 3D surface information.

9099-17, Session 4

Quantification of image registration error

Adoum H. Mahamat, Univ. of Arizona (United States); Eric A. Shields, Sandia National Labs. (United States)

Image registration is a digital image processing technique that takes two or more laterally displaced images of scene and transforms them into a single coordinate system. Frequently, image registration is used in remote sensing to fuse images from different satellites or multi-spectral image. For that reason, image registration accuracy is very crucial. While image registration is usually performed on intensity images, one can do the registration using metric images as well. This paper will present registration methods and their accuracies for various noise levels for the case of pure translational image motion. Registration techniques will be applied to intensity images, phase congruency images, gradient images, and Canny edge-detected images. Another thing that this study will investigate is the registration of low resolution versions of the previous images; basically we will determine the registration error of the under-sampled versions of those images. Noise-free images are degraded by Gaussian noise as well as a fixed-pattern noise. The registration error is quantified and compared to each method. In this study, two registration techniques were used. The first one is a discrete Fourier transform (DFT) registration technique and the second method is a fast Fourier transform technique. The results of both methods were compared to each other to determine their registration errors.

9099-18, Session 4

Spatial calibration of full stokes polarization imaging camera

Mathieu Vedel, Sebastien Breugnot, Nicolas Lechocinski, Bossa Nova Technologies (United States)

Objective and background: We present a new method for the calibration of Bossa Nova Technologies' full Stokes, passive polarization imaging camera SALSA. The SALSA camera is a Division of Time Imaging Polarimeter. It uses custom made Ferroelectric Liquid Crystals mounted directly in front of the camera's CCD. Regular calibration process based on Data Reduction Matrix calculation assumes a perfect spatial uniformity of the FLC. However, alignment of FLC molecules can be disturbed by external constraints like mechanical stress from fixture, temperature variations and humidity. This disarray of the FLC molecules alignment appears as spatial non-uniformity. With typical DRM condition numbers of 2 to 5, the influence on DOLP and DOCP variations over the field of view can get up to 10%. Spatial non-uniformity of commercially available FLC products is the limiting factor for achieving reliable performances over the whole camera's field of view. We developed a field calibration technique based on mapping the CCD into areas of interest, then applying the DRM calculations on those individual areas.

Results: First, we provide general background of the SALSA camera's technology, its performances and limitations. Detailed analysis of commercially available FLCs is described. Particularly, the spatial non uniformity influence on the Stokes parameters. Then, the new calibration technique is presented. Several configurations and parameters are tested: even division of the CCD into square-shaped regions, the number of regions, adaptive regions. Finally, the spatial DRM "stitching" process is described, especially for live calculation and display of Stokes parameters.

9099-19, Session 4

Calibration methodology and performance characterization of a polarimetric hyperspectral imager

Kevin C. Gross, Air Force Institute of Technology (United States) and Polaris Sensor Technologies, Inc. (United States)

Polarimetric hyperspectral imaging (P-HSI) has the potential to improve target detection, material identification, and background characterization over conventional hyperspectral imaging and single-band polarimetric imaging. To fully exploit the spectro-polarimetric signatures captured by such an instrument, a careful calibration process is required to remove the spectrally- and polarimetrically-dependent system response (gain). Calibration of instruments operating in the long-wave infrared (LWIR, 8-12 μm) is further complicated by the polarized spectral radiation generated within the instrument (offset). This paper presents a calibration methodology developed for an LWIR Telops Hyper-Cam modified for polarimetry by replacing the entrance window with a holographic wire-grid polarizer (4000 lines/mm, ZnSe substrate, 350:1 extinction ratio). Specifically, a Mueller-matrix approach is developed and polarized self-emission is accounted for at each optical interface. We demonstrate that under the ideal polarizer assumption, two distinct blackbody measurements at polarizer angles of 0°, 45°, 90°, and 135° are sufficient to calibrate the system for apparent degree-of-linear-polarization (DOLP) measurements. Noise-equivalent S1, S2, and DOLP are quantified using a wide-area blackbody. Spectro-polarimetric performance is characterized via measurements of specularly-reflected blackbody radiation from an optically-polished Silicon Carbide (SiC) wafer. SiC exhibits strong Reststrahlen features in the LWIR, and our measurements are compared with theoretical predictions based on the complex index of refraction determined from ellipsometry measurements of the same wafer.

9099-40, Session 4

Phase error in Fourier transform spectrometers employing polarization interferometers

Julia M. Craven-Jones, Sandia National Labs. (United States); Michael W. Kudenov, North Carolina State Univ. (United States)

Fourier transform spectrometers exploit interferometric techniques and are widely used for obtaining spectral data products. Conventionally, Fourier transform spectrometers employ a Michelson interferometer, and recovery of the spectral data typically includes a phase correction algorithm that compensates for phase errors in the collected interferogram. Unfortunately, phase correction can be exacting and computationally intensive, in particular if a single sided interferogram is acquired. However, polarization interferometers using Wollaston prisms and Savart plates have been used recently to produce more compact and rugged Fourier transform spectrometers. Because polarization interferometers lack the components that typically produce the majority of phase errors in reflective interferometers, namely beam splitters and moving mirrors, Fourier transform spectrometers that employ polarization interferometers may be less susceptible to phase errors than those using Michelson interferometers. If polarization interferometers are subject to negligible phase error, phase correction can potentially be omitted and a nearly single sided interferogram can be collected. This paper examines the phase error artifacts produced by Fourier transform spectrometers that employ polarization interferometers. Additionally, the three most commonly implemented phase correction algorithms are implemented on polarization interferometer data, and the residual phase errors are compared.

9099-20, Session 5

Five-dimensional optical instrumentation: combining polarimetry with time-resolved integral-field spectroscopy

Michiel Rodenhuis, Frans Snik, Gerard van Harten, Jens Hoeijmakers, Ronniy Joseph, Christoph U. Keller, Leiden Univ. (Netherlands)

We present implementations of optical instrumentation that records five dimensions of light: polarization as a function of wavelength, two spatial dimensions, and time. We focus on the optimal integration of polarimetry within microlens-based integral-field spectroscopy. The polarimetric analyzer (or beam-splitter) and dispersing element could be implemented separately, but also amalgamated in the form of a polarization grating. We present optimizations for stacking the polarization-split spectra on a 2D detector. The polarimetric modulation can be performed in the temporal domain or the spectral domain. Temporal modulation could be set up with achromatic optics conform the Stokes definition scheme, but a wide wavelength range generally demands a "polychromatic" modulation approach for which the modulation efficiency for all or some of the Stokes parameters is optimized at every wavelength. Spectral modulation (full-Stokes or optimized for linear polarization) yields instruments without any moving parts, for which all polarization information is obtained in one shot.

We present first results from two polarimetric IFU instruments; ExPo-IFU and LOUPE. The first is based on a rapid polychromatic modulator consisting of two FLCs and two fixed retarders, while the latter is based on spectral modulation for linear polarization. In addition to applications within astronomy and planetary science, we discuss remote-sensing applications for such instruments.

9099-21, Session 5

Birefringent snapshot imaging spatial heterodyne spectrometer

Michael W. Kudenov, Bryan Maione, David Luo, Matthew N. Miskiewicz, Michael J. Escuti, North Carolina State Univ. (United States)

Fourier transform spectrometers are capable of higher spectral resolution when compared to their dispersive counterparts. However, compared to dispersive sensors, FTSs contain sampling limitations in that their spectral resolving power can not be easily traded off against the system's spectral passband. Ultimately, spatial heterodyne interferometers (SHIs) are able to circumvent this limitation. In this paper, a new birefringent SHI is discussed which, for the first time, is capable of snapshot imaging spatial heterodyne interferometry. The SHI is based on a previous implementation of a Shapshot Hyperspectral Imaging Fourier Transform (SHIFT) spectrometer. As such, the spectrometer is compact and mountable directly to a focal plane array. Details of the instrument are provided, as well as calibration procedures and apparati. Finally, the sensor's performance is also highlighted and the spatial heterodyning capability of the sensor is assessed. This sensing capability could be leveraged in future applications, including Fraunhofer line discrimination and chemical detection.

9099-22, Session 5

Development of spectropolarimetric imagers from 400 to 1700 nm

Neelam Gupta, U.S. Army Research Lab. (United States)

Development of two prototype hyperspectral imagers that also collect polarization signatures is being carried out in the visible-near infrared (VNIR) and shortwave infrared (SWIR) regions. Each of these imagers uses a noncollinear acousto-optic tunable filter (AOTF) and two liquid crystal variable retarders (LCVRs). The spectral region of operation for the first imager is from 400 to 800 nm and the second one from 900 to 1700 nm. We will present the optical design and analysis results.

9099-23, Session 5

Exploring polarimetric hyperspectral imaging as a tool for improved material identification

Kevin C. Gross, Air Force Institute of Technology (United States)

A new research effot is underway to investigate the degree to which polarimetric hyperspectral imaging (P-HSI) improves material identifiation over conventional hyperspectral imaging. To that end, the en-trance window of a Telops LWIR (8-12 μm) hyperspectral camera was modified to incorporate a holographic wire-grid polarizer (4000 lines/mm, ZnSe substrate, 350:1 extinction ratio). To assess instrument performance and data reduction methods, preliminary measurements of an uncoated glass (BK7) cylindrical lens and an uncoated quartz window were made. In the LWIR, polarimetric measurements require careful two-point radiometric calibration to remove the effects of polarized system response (gain) and polarized instrument self-emission (offset). This was accomplished using on-board wide-area blackbodies which precede and overfill the polarizing element. Treating the polarizer as ideal, degree-of-linear-polarization (DOLP) spectra are formed from the appropriate apparent spectral radiances measured at polarizer angles of 0°, 45°, 90°, and 135°. Both unpolarized (S0) and DOLP spectra are compared to theoretical predictions based on known surface-normal angles and spectrally-resolved complex indices of refraction. Implications for material identification are discussed.

9099-24, Session 5

IR polarimetric camcorder

David B. Chenault, John S. Harchanko, Joseph L. Pezzaniti, Brian Hyatt, Todd Aycock, Justin P. Vaden, Polaris Sensor Technologies, Inc. (United States)

The instrumentation for measuring infrared polarization signatures has seen

significant advancement over the last decade. Previous work has shown the value of polarimetric imagery for a variety of target detection scenarios including detection of manmade targets in clutter and detection of ground and maritime targets while recent work has shown improvements in contrast for aircraft detection and biometric markers. These data collection activities have generally used laboratory or prototype systems with limitations on the allowable amount of target motion or the sensor platform and usually require an attached computer for data acquisition and processing. Still, performance and sensitivity have been steadily getting better while size, weight, and power requirements have been getting smaller enabling polarimetric imaging for a greater or real world applications.

In this paper, we describe the Polaris IR Polarimetric Camcorder, a handheld infrared imaging polarimeter, that produces live polarimetric video for several polarization products. The system is immune to motion artifacts of either the sensor or the scene. The system is battery operated, rugged, and weighs about one pound and can be helmet mounted or handheld. The operator views the polarization products in real time on either a helmet mounted display or small external display integrated with a digital video recorder. Polarization sensitive microbolometers are used to produce, at a minimum, S0 and S1 polarization products. A top level description of the camcorder is given followed by performance characteristics and representative data.

9099-25, Session 6

A novel IR polarization staring imaging system designed by a four-camera-array

Xiaopeng Shao, Fei Liu, Pingli Han, Xidian Univ. (China)

A novel IR polarization staring imaging system employing a four-camera-array is designed for target detection and recognition, especially man-made targets hidden in complex battle field. The design bases on the existence of the difference in infrared radiation's polarization characteristics, which is particularly remarkable between artificial objects and the natural environment. The system designed employs four cameras simultaneously to capture the polarization difference to replace the commonly used systems engaging only one camera. Since both types of systems have to obtain intensity images in four different directions (I0 , I45 , I90 , I-45), the four-camera design allows a better real-time capability and lower error without the mechanical rotating parts which is essential to one-camera systems. Information extraction and detailed analysis demonstrate that the caught polarization images include valuable polarization information which can effectively increase the images' contrast and make it easier to segment the target even the hidden target from various scenes.

9099-26, Session 6

Beyond polarization microscopy: Mueller matrix microscopy with frequency demodulation

Oriol Arteaga, Ertan Kuntman, Marta Baldrís, Juan Antó i Roca, Adolf Canillas Biosca, Enric Bertran Serra, Univ. de Barcelona (Spain)

Mueller matrix microscopy provides images of the Mueller matrix of a sample with micrometric resolution. In this work we describe a Mueller matrix microscope that uses that uses the dual rotating compensator technique to simultaneously determine all the elements of the Mueller matrix. The two compensators continuously rotate at different frequencies and every Mueller matrix element is determined using a digital synchronous detection technique in which the time dependent intensity captured at every pixel of the CCD detector is frequency-analyzed. A typical measurement is completed in a little over a one minute and it can be done at any wavelength of the visible range. The sensitivity is better than the 0.5% for all the elements of the Mueller matrix and the spacial resolution is around 2 microns.

Polarized Light Microscopy has a vast number of applications in geology, biology, chemistry, etc. In most of these fields the main optical effect under study is the linear birefringence, but its determination is only semi-quantitative because it is based on the visual analysis of the interference polarization colors, and their comparison with the Michel-Levy interference color chart. Mueller matrix microscopy is the natural generalization of Polarized Light Microscopy because it brings quantitative results and allows the determination of linear birefringence, linear dichroim, circular birefringence, circular dichroism and depolarization. In this work we show some applications of the microscope, for example to study the subpixel components of liquid crystal displays and to reveal the polarizing characteristics of some insect wings.

9099-27, Session 6

Polarized standoff thermal hyperspectral imaging of minerals and materials

Marc-André Gagnon, Vincent Farley, Pierre Tremblay, Simon Savary, Martin Chamberland, Telops (Canada)

The capabilities of the Telops Hyper-Cam, a commercially available standoff infrared hyperspectral imaging system, can now be extended using its new motorized polarizer accessory. This additional implement, installed in the instrument for-optics, allows easy investigation of scenes using a plane-polarized filter. Polarization plane is user-selectable over a 360 degrees range with an accuracy of 0.1 degree. In this paper, polarized thermal hyperspectral imaging is used to investigate various scenes containing minerals and man-made objects. In addition, the reflective character of ice is highlighted in an experiment involving freshly made snow-tracks. The unique properties of some materials to selectively absorb/emit or reflect plane-polarized infrared radiation as a function of wavelength are discussed. The results illustrate how wavelength-selective infrared plane-polarization brings additional information allowing discrimination of optically-active materials from their background.

9099-28, Session 6

Integrated quantitative multispectral polarimetric immunohistochemistry (IHC) of lung cancer tissue microarrays

George C. Giakos, Tri Quang, Tannaz Farrahi, Chaya Narayan, Aditi Deshpande, Suman Shrestha, Na Ying, The Univ. of Akron (United States)

The purpose of this study is to develop efficient and reliable techniques for early identification and discrimination of precancerous and cancerous lung cells that can lead to accurate diagnosis and treatment of lung cancer.

Immunohistochemistry (IHC) plays an essential role in clinical laboratories. In order to improve reliable reproduction and standardization of the results outcomes, with high accuracy, quantification methods have been developed, based in whole slide imaging or virtual microscopy. IHC is of paramount significance in the assessing in situ of protein expression, correlating morphological and molecular signatures, while predicting the response to targeted therapies.

Cancer changes at cell level occur in the shape, size, and orientation of the nuclei, an increase in nucleus chromatin content, variations in the nucleus-cytoplasmatic ratio and changes in the cytosolic content. Polarimetric imaging can provide both quantitative morphological, biochemical and metabolic information of the neoplastic changes.

In this study, the design principles of a multispectral polarimetric imaging system for Immunohistochemistry (IHC) of Lung Cancer Tissue Microarrays will be introduced and related to operating conditions and system performance metrics. Preliminary results indicate that high contrast, high-specificity images can be obtained by integrating polarimetric principles and artificial intelligence.

9099-29, Session 7

Modeling of a polarization tag for hydrogen fluoride gas monitoring

Adoum H. Mahamat, College of Optical Sciences, The Univ. of Arizona (United States); Julia M. Craven-Jones, Sandia National Labs. (United States); J. Scott Tyo, College of Optical Sciences, The Univ. of Arizona (United States)

Polarization imaging is a commonly implemented imaging technique for remote target identification. Frequently, polarization imaging exploits the natural polarization signature of a target for identification. Alternatively, an artificial polarization signature can be generated to provide for identification of a target that does not inherently possess a polarization signature. A polarization tag that experiences a change in its polarization properties when exposed to hydrogen fluoride (HF) gas is under development at Sandia National Laboratories. In this paper, we present the results of modeling the optical properties of the polarization tag element using a rigorous coupled wave analysis. The tag is modeled as a periodic structure using several materials in combination with a silicon substrate, and the tag is analyzed to determine the change in the optical response - mainly the diffraction efficiency for the cases when the tag is exposed and unexposed to HF gas. This analysis is used to determine the polarization properties of the optical response of the tag as a function of its physical and electromagnetic properties, the best optical pass-band for interrogating the tag, as well as the nominal polarization for the illumination source.

9099-30, Session 7

On the accuracy of broadband circular polarization signatures

Michael G. Gartley, Rochester Institute of Technology (United States)

Circular polarization in the visible and near-infrared (VNIR) region of the electromagnetic spectrum is often not considered worthy of measurement based on the expected scarcity in passive remote sensing situations. Additionally, common optical components (such as retarders) utilized to discriminate circular polarization may be sensitive to wavelength making broadband measurements challenging. Utilizing a single quarter-wave plate retarder for discrimination of broadband circular polarization signatures can produce errant results in many situations. With the recent growth of the smart-phone and solar panel technologies, the thin-film surfaces of many devices present a new class of targets that might be tagged and tracked via circular polarization signatures. The presented research will describe a new approach for estimating a level of confidence in measured circular polarization signatures as a function of channel bandwidth.

9099-31, Session 7

Polarization analysis of target imaging in an underwater environment

Yalong Gu, Alexander Gilerson, Carlos Carrizo, Amir Ibrahim, Samir Ahmed, The City College of New York (United States)

Imaging of targets in underwater environments is a challenging task. Traditional imaging instruments only record irradiance patterns. However, underwater light fields are usually partially polarized. Recently developed full Stokes vector imaging cameras can record the polarization pattern of a scene. As polarization contains more information than simple irradiance, such capabilities provide an advanced tool for underwater imaging, where one of the basic problems in image formation is determination of a point spread function. While so far, most studies have focused on scalar point spread functions, in this work we use a Monte Carlo technique to simulate the vector point spread function - namely the distribution of the four Stokes parameters in the receiver plane for a point source, with given polarization state, for a broad range of water parameters from clear to turbid coastal waters.

Since the polarized light field at the receiver plane is a combination of light from the target and light scattered by suspended particles between the target and the camera, also known as veiling light, we analyze the impact of the veiling light on the image together with the light from the target for varying reflectance and polarization properties. The knowledge acquired from this forward process is expected to contribute to solutions of the inverse problem of the restoration of the target polarization characteristics from its underwater image. Results of these simulations are compared with the imaging of polarized targets with the full Stokes vector camera together with measurements of water optical properties for varying water conditions.

9099-32, Session 7

Analysis of the detectable range of infrared polarization imaging system used in sea-surface environment

Runqiu Xia, Xia Wang, Weiqi Jin, Jianan Liang, Beijing Institute of Technology (China)

Polarization imaging system has been used in a variety of applications, including medical imaging, remote sensing, target detection, and so on. It has been proved by experiment that the vector nature of optical radiance (visible and infrared) from sea surface is polarized. It is thus possible to use the infrared polarization imaging system to detect target on the sea surface by the differences between the polarization states of target and sea-surface background. For evaluating this application, the detectable range of infrared polarization imaging system used in sea-surface environment is analyzed in this paper. An infrared radiative transfer model of the sea surface is created. The classic infrared radiative transfer model of the sea surface is based on numerical computation using sea surface slope probability density and quasi-specular method. A reversed ray trace method is used in this paper to replace the numerical computation way. Elfouhaily's omnidirectional wave spectrum and Malcolm Heron's spreading shape function is utilized to reconstruct the sea surface in this model. The boundary of reversed ray transfer paths which are traced is the field of view of the imaging system. The paths are original in the imaging system, reflected by the sea surface and stop when reenter the sky. The incident radiation from the sky and spontaneous activity emission of the sea surface is combined with the Muller matrix of reflection points to calculate the total radiation that leaves the sea surface to the imaging system. Effect from the atmosphere on the radiance transfer is taken into account. Considering of computing time, Monte-Carlo method is not used to simulate the radiation transfer characteristics of atmosphere (the depolarization effects of the atmosphere are ignore) in this paper, only total radiation absorbed/transferred and radiation emitted by atmosphere are counted. According to the method mentioned above, the radiation reaching the polarization imaging system from sea surface and target on the sea surface are obtained. A polarization imaging system used Pickering method (four channel including 0,45, 90, 135 degrees) is acting as an example. Standard error propagation techniques are used to calculate the noise characteristics of the component of Stokes vector imaging (I, Q, U). Because MRTD (Minimum resolvable temperature difference) of an infrared intensity imaging system is directly proportional to its random time spatial noise, we can obtain the new MRTD respectively for the components: I, Q, U. Radiation differences in the I, Q, U images is converted to blackbody equivalent temperature differences. When size and polarization state of the target are set, the radiation difference of Stokes vector I, Q, U between target and sea surface background is calculated with changing the distance between polarization imaging system and sea surface, . By equalizing the new MRTD and equivalent temperature differences of Stokes vector, the maximum detectable range is calculated at last.

9099-33, Session 8

Multiband retardation control using multitwist retarders

Kathryn J. Hornburg, Ravi K. Komanduri, Michael J. Escuti, North Carolina State Univ. (United States)

We introduce and demonstrate an approach to create highly chromatic retardation spectra passively across various wavelengths. The design approach is based on Multi-Twist Retarder (MTR) principle where multiple liquid crystal polymer layers are coated on top of each other on a single substrate. Several conventional approaches exist, such as Solc and Evans birefringent waveplate assemblies. Each involve multiple elements that are created individually and aligned precisely, which not only increases challenges with alignment and designing but also decreases maximum transmission performance. Using MTR filters removes these challenges, as all the alignment is accomplished by the device itself with a single alignment step.

Previously, MTRs have been applied to develop broadband achromatic retarders. But here we show that MTRs are quite flexible, and their retardation spectrum can be tuned to create arbitrary profiles. As a representative example, we show this tailorability by creating a retarder which produces zero retardation in visible (VIS, 500-900 nm) and half-wave retardation in near-infared (NIR, 1-2.7 μm). This means this single optic behaves as a retarder in NIR but appears transparent at VIS, a capability that can be adapted for filters, beam combiners, and much beyond. Experimentally, we have also patterned this birefringent layer so that its optical axis varies linearly, to create a multiband Polarization Grating (PG) that diffracts highly in NIR (>80%), while is highly transmissive in VIS (>80%). This may be important to several applications in defense, telecom, and spectroscopy systems where it is advantageous to have an optical element which affects only one band, but is largely transparent otherwise.

9099-34, Session 8

Liquid crystals for polarization control in the MWIR

Erika Petrak, Thomas G. Baur, Meadowlark Optics, Inc. (United States)

Liquid crystal technology, an established key element in a diverse range of optical components for visible wavelengths, has recently been adopted into products for the mid-wave infrared (MWIR). Liquid crystal optics have long been favored for their non-mechanical tunability, ease of use, and simple streamlined design, but have been noticeably absent in tunable optics for the MWIR. This void has crippled many applications in defense and remote sensing. Meadowlark Optics' development of liquid crystal components tunable over 3.6 to 5.7 um promises light-weight, mobile designs with low power requirements and precise analog tunability. Liquid crystal variable retarders are offered to fit in compact housings with no moving parts, doing away with heavy, cumbersome set-ups and vibrational errors common to the only other MWIR alternative, fixed waveplate assemblies. These solutions provide continuous retardance ranging from 0.06λ to 1λ with a 0-10V control adjustment, despite the difficulty of achieving sufficient stroke at such long wavelengths. Germanium substrates minimize the MWIR absorptions typically seen in liquid crystal devices. Product potential extends into variable attenuators, polarization rotators, and tunable wavelength filters, making the benefits of liquid crystal devices readily available for a broader range of MWIR applications.

9099-35, Session 8

First prototypes of vortex retarders obtained by polarization holography

Pierre Piron, Pascal Blain, Univ. de Liège (Belgium); Dimitri P. Mawet, European Southern Observatory (Chile); Serge Habraken, Univ. de Liège (Belgium)

At this conference, we will present the first prototypes of vortex retarders made of photo-orientable liquid crystals polymers recorded by polarization holography and without mechanical action.

Vortex retarders are birefringent plates characterized by a uniform phase retard and a rotation of their fast axis along their center.

Liquid crystals are anisotropic molecules possessing birefringent properties. They are locally orientable and their orientation defines the fast axis orientation of the retarder. Their alignment depends on the local orientation of the recording electric field.

The superimposition of several polarized beams will be used to shape the electric field to achieve the recording of vortex retarders. The mathematical aspects of the superimposition process, as well as several numerical simulations are exposed.

Then the first prototypes are presented, characterized and compared to the numerical simulations.

Finally, several applications of these retarders are discussed.

9099-36, Session 8

Imaging with photoelastic modulators

John Freudenthal, Hinds Instruments, Inc. (United States); Shane Nichols, New York Univ. (United States); Oriol Arteaga, Univ. de Barcelona (Spain); Bart Kahr, New York Univ. (United States)

Many polarimeters use photoelastic modulators (PEMs) that dynamically vary their retardance with time hence; they modulate the polarization state of light. However, they do so at frequencies well above what can be sampled by 2D imaging detectors. Thus, clever techniques are required to make PEMs compatible with imaging polarimeters. Han and Chao introduced the first such technique in 2006, stroboscopic illumination that combined a CCD camera with a high frequency light source to synchronously deliver pulses of light at particular phases of the PEM. By making the light pulses narrow with respect the PEM modulation period, the temporally varying retardance of the PEM was essentially frozen in time, and therefore the PEM could be modeled as a static retarder. More recently, Vitkin et al. constructed a polarimeter with two PEMs that gated a detector rather than a light source. The problem with the aforementioned methods is that they suffer from poor light throughput. For multiple modulator instruments, the narrow pulses of light must be delivered when the phases of multiple modulators coincide, thus the light is almost never on. The method is not suitable for applications that require high light throughput (scattering, reflectivity, fluorescence, etc.), and likely cannot be extended to polarimeters with more than two PEMs, where the phases of several PEMs would need to coincide. We propose a new imaging method that does not suffer from low light throughput, and can be used with our four-modulator polarimeter.

9099-37, Session 8

A polarization-sensitive mid-infrared plasmonic absorber for multiband resonance

Yongqian Li, Binbin Wang, Zili Zhou, Northwestern Polytechnical Univ. (China)

Plasmonic Absorption metamaterials made from metallic nanoantenna and dielectric nanostructures have gained tremendous interest during the last decades. If resonantly excited by electromagnetic field, plasmonic absorbers show a strong localized field enhancement in the vicinity of the metal surface and a distinct spectral response. Such optical properties of field enhancement and spectral selectivity promise great applications for increasing the efficiency of photovoltaics, sensitive photodetection, light-emitting devices, and optical sensors1.

The multiple spectral responses of Plasmonic Absorption Metamaterials

(PAMs) attract great attention due to their exciting scientific and practical applications. For realization of narrow multi-band absorption in desired frequency regions, numerous nanostructures have been proposed and investigated. The narrow-band response and its tunability of PAMs have been achieved in frequency from terahertz wave, to infrared and even visible light. Over entire mid-infrared range, PAMs have been investigated with single-band24, dual-band25, triple-band and broad-band absorptions.

In this paper, one dual-cross shaped PAMs was developed and investigated to achieve triple-band responses in mid-infrared region for the purpose of quantitative multiple spectral detection. This PAMs possess three distinct resonance peaks standing independently, which are attributed to plasmonic resonant excitation of perpendicular polarization light. The optical parameters retrieved by S-parameters method were investigated, which provides a satisfactory qualitative description of the multiple-band spectra responses. On the other hand, based upon the microscopic perspective, the redistributions of near-field intensity within PAMs structure were probed theoretically and numerically, which also explained the multiband absorption behavior of the PAMs ensemble. The proposed structure holds promise for application of multi-bands sensitive photodetection in infrared region.

9099-38, Session 8

Polarimetric evaluation of commercial pellicles and beamsplitter

Dennis H. Goldstein, Jennifer L. Massman, David G. Edwards, Air Force Research Lab. (United States)

Three commercial beamsplitting elements, two pellicles and a beamsplitter, have been evaluated in a spectropolarimeter. Evaluation was accomplished from 0.4 to 14 micrometers. Mueller matrix results are presented.

9099-39, Session Posters-Tuesday

A 250-frames-per-second 640 by 480 pixels division of focal plane polarimeter for the visible spectrum

Timothy York, Viktor Gruev, Radoslav Marinov, Washington Univ. in St. Louis (United States)

The most common method of polarimetery involves imaging a scene through a polarization analyzer at multiple configurations. Switching among these configurations requires capturing multiple images of the scene, limiting the ability to capture real-time polarization data due to multiple scene sampling and motion artifacts. Advances in fabrication technology have allowed direct integration of polarization analyzers onto the sensor, enabling the capture of multiple analyzer intensities from a single frame. Using this technique, we have fabricated a high frame rate, VGA resolution, division of focal plane polarization imager for the visible spectrum. The imaging sensor is realized by monolithic integration of aluminum nanowires with an array of CCD imaging elements. The pixelated nanowire polarization filters are at four different orientations offset by 45 degrees. This allows for recording of the first three Stokes parameters at every super pixel, and subsequently the degree of linear polarization and angle of polarization are computed at 250 frames per second at full VGA resolution and over 1000 when limited to a subsection of the array. The imaging sensor also employs a per pixel calibration scheme which mitigates the variations in the aluminum nanowire sizes. We present a full optical characterization of the sensor, analyzing the accuracy of the measured degree and angle of polarization, as well as providing complete spectral measurements over the sensor's operating range of 400 to 700 nanometers. Additionally, we will utilize the increased frame rate to capture high speed polarization phenomena that are only visible at high frame rates.

9099-41, Session Posters-Tuesday

How do sorghum plants polarize incident light

Vern C. Vanderbilt, NASA Ames Research Ctr. (United States); Craig S. T. Daughtry, U.S. Dept. of Agriculture (United States); Larry L. Biehl, Purdue Univ. (United States)

We tested the hypothesis that the polarization of light incident on a plant canopy is modified during a quasi specular reflection by the first surface the light encounters - the leaf cuticle. We constructed a tower 5.9m tall in the center of a homogenous sorghum field in the flowering development stage. We equipped two Barnes MMR radiometers with polarization analyzers at 0°, 45° and 90° on the blue, red and 2.08-2.35um Landsat TM wavelength bands. The 0.76-0.90 μm TM wavelength band was left unpolarized. We collected radiance data in 44 view directions - view zenith angles of 0, 15, 30, 45, 60 and 65 degrees and view azimuth angles of 0, 45, 90, 135, 180, 225, 270, and 315 degrees – multiple times as the sun tracked across the sky during two days of data collection. Our experimental results support our hypothesis, showing that the angle of polarization in the red wavelength region may be predicted based upon the solar direction during clear sky but not overcast sky conditions; and that ratios of results for the red and blue wavelength bands are close to 1.0 during overcast sky conditions but not during clear sky conditions.

9099-42, Session Posters-Tuesday

Design and calibration of a full-stokes polarimeter with KD*P crystals

Junfeng Hou, National Astronomical Observatories (China)

A new full-Stokes polarimeter with Deuterated Potassium Dihydrogen Phosphate (KD*P) crystals was developed. This paper describes the design principle, optimization method, and high-precision calibration of the polarimeter. The polarimeter consisting of two KD*Ps and a fixed retarder has four states, the minimum required to allow recovery of the full-Stokes vector, and a flexible modulation frequency from 1 Hz to 1 kHz. It is optimized by minimizing the demodulation matrix of polarimeter's instrument matrix, introduced by J.C. del Toro Iniesta and M.Collados [Applied Opitics, 39(10), 1637 (2000)], so that it has the best polarization measurement efficiencies at the spectra range of 400-900 nm. We also present and discuss here a new calibration method, the non-linear least square fitting method, to calibrate the polarimeter's instrument matrix. The polarimeter and its calibration system were established in laboratory, and its instrument matrix was calibrated. The results showed that the measuring accuracy of the full-stokes polarimeter is better than 0.025 over all the spectra range 400-900 nm.

9099-43, Session Posters-Tuesday

Polarized light imaging of the human brain: a new approach to the data analysis of tilted sections

Hendrik Wiese, Melanie Dohmen, Julia Reckfort, David Graessel, Uwe Pietrzyk, Katrin Amunts, Markus Axer, Forschungszentrum Jülich GmbH (Germany)

3D-Polarized Light Imaging (3D-PLI) has been demonstrated to be an excellent tool for mapping the nerve fiber architecture in postmortem human brains at sub-millimeter resolution. 3D-PLI is applied to unstained histological brain sections and enables to extract the predominant 3D fiber orientation for each image pixel of a section by utilizing the intrinsic tissue birefringence. The determination of the fiber orientation out of the sectioning plane (i.e. the fiber inclination) is particularly challenging due to the dependency on the local fiber density. This becomes obvious at the white matter / gray matter border, where the fiber density, and thus the degree of birefringence, change gradually. With the currently used 3D-PLI data analysis, this change might lead to an over-estimation of the fiber

inclination.

In this study, we introduce a new analysis method which accounts for variances in the degree of birefringence by utilizing the in-house developed polarimetric device equipped with a tiltable specimen stage. It is demonstrated how the data obtained from tilting measurements is processed by means of a Fourier analysis to reconstruct the fiber inclination independently from varying fiber densities in the brain.

The developed algorithm was optimized for fast computation and showed good noise stability when applied to simulated data sets. Subjecting experimental data to the algorithm revealed significant improvements of the reconstructed fiber orientations in the cerebral cortex. Thus fibers which in the past were misinterpreted as being nearly orthogonal with respect to the sectioning plane, are now demonstrated to be oriented in the lateral direction.

9099-44, Session Posters-Tuesday

Polarization signatures: a sampling of phenomenology and applications

David B. Chenault, J. Larry Pezzaniti, Polaris Sensor Technologies, Inc. (United States)

Infrared polarization relies on surface temperature, roughness, material properties, aspect angle to the sensor, sky down-welling and background radiance reflecting from the target. Each of these factors can contribute to make thermal and / or polarization signatures strong or conspire to minimize both. We stress here situations in which the polarization signature of a manmade target is significantly different than the surrounding background. This paper will present maritime, airborne and ground data sets of polarization signatures of several objects that allow detection when other methods fall short.

9099-45, Session Posters-Tuesday

A single-instrument multi-ellipsometer system: single-element polarizer-ellipsometer (SEP ellipsometer)

A. R. M. Zaghloul, M. Elshazly-Zaghloul, Univ. of Cairo (Egypt)

We present a collective, integrative view and a comprehensive, detailed analysis of the Single-element Polarizer-ellipsometer (SEP Ellipsometer), where the ellipsometer is composed of only a polarizer in the incident beam. A light detector receives the reflected beam from the sample, which is a film-substrate system in general. Three modes of operation of this single-instrument multi-ellipsometer system exist. First: the polarizer is rotated and the angle of incidence is scanned for a specific condition of the detector signal. That way, specific points on the ?-plane of the film-substrate sample are detected. Second: the polarizer is rotated where the angle of incidence is kept un-changed, and the ac/dc ratio is detected, yielding the ellipsometric angle ? of the sample. Third: the angle of incidence is scanned, while the polarizer is stationary, and a specific condition of the detector signal is detected, indicating a related specific condition of the sample performance. For all modes of operation, heuristic and/or mathematical inversion methods exist to fully characterize the film-substrate system: determine the substrate optical constant and that of the film, in addition to the film thickness, or a subset thereof. We present and discuss the available inversion methods with examples as applied to the SiO_2-Si film-substrate system.

9100-1, Session 1

Architectures for gigapixel video *(Keynote Presentation)*

David J. Brady, Duke Univ. (United States)

While multiscale optical designs allow the construction of digital cameras scaling from 250 megapixels to 50 gigapixels, electronic sensing, processing and communication requirements remain significant barriers to large camera construction and operation. Air cooled operation of a gigapixel video camera requires that less than 1 W of power be expended per gigapixel, a 100x improvement over early camera prototypes. This talk reviews available ASIC read-out and processing solutions and considers physical and digital layer compression strategies to enable gigapixel video in persistent security systems.

9100-2, Session 1

Uncooled microbolometers at DRS in 2014 *(Invited Paper)*

George D. Skidmore, Chien-Jih Han, DRS Technologies, Inc. (United States); Chuan C. Li, N2 Imaging Systems, LLC (United States)

DRS history in microbolometer and uncooled focal plane array (UFPA) development mimics that of the entire industry. The history extends over fifteen years as array pitches moved ever-smaller from 51um to 25um to 17um, and now something smaller than 17um. The DRS microbolometer uses the well-known Vanadium Oxide as a transducer material. But the DRS UFPAs use a unique and patented two-layer microbolometer design to maximize fill-factor for high optical absorption. While the two-layer design contributes to larger heat capacity, it absorbs more radiant flux and results in improved NETD.

DRS, along with the industry, has transitioned through smaller pitches about every six years. This has been done while maintaining a noise equivalent temperature difference (NETD) performance of 20-50mK, and maintaining a thermal time constant (TTC) of 10-20mSec. Once a newer pitch is developed to a performance level matching the previous pitch, development on the next smaller pitch is already underway. In this manner, the industry has progressed through smaller pitches without a fundamental performance improvement when measured in NETD or in TTC, or more specifically in NETD*TTC product. Hence, a more-encompassing metric for tracking performance through time would involve the NETD, the TTC, and the array pitch or microbolometers area. The paper will propose and discuss the NETD*TTC*Area metric for the history of the uncooled microbolometer.

The smaller pitch has enabled lower cost arrays, and therefore lower cost infrared cameras for ever-increasing applications. The new applications are being enabled by both the lower cost and the smaller sized infrared cameras enabled by smaller pitches. For example, the DRS Tamarisk product line was enabled by the pitch reduction from 25um to 17um. For the future, DRS is working on the Low-Cost-Thermal-Imager (LCTI) program sponsored by DARPA for small form-factor infrared cameras using a pitch smaller than 17um.

9100-3, Session 1

Performance of PHOTONIS' low light level CMOS imaging sensors for long range observation

Loig E. Bourree, PHOTONIS USA (United States)

Identification of potential threats in low-light conditions through imaging is commonly achieved through closed-circuit television (CCTV) and surveillance cameras by combining the extended near infrared (NIR) response (800-10000nm wavelengths) of the imaging sensor with NIR LED or laser illuminators. Consequently, camera systems typically used for purposes of long-range observation often require high-power lasers in order to generate sufficient photons on targets in order to acquire detailed images at night. While these systems may adequately identify targets at long-range, the NIR illumination needed to achieve such functionality can easily be detected and therefore may not be suitable for covert applications. In order to reduce dependency on supplemental illumination in low-light conditions, the frame rate of the imaging sensors may be reduced so as to increase the photon integration time and thus improve the signal to noise ratio of the image. However, this may hinder the camera's ability to image moving objects with high fidelity. In order to address these particular drawbacks, PHOTONIS has developed a CMOS imaging sensor (CIS) with a pixel architecture and geometry designed specifically to overcome these issues in low-light level imaging. By combining this CIS with field programmable gate array (FPGA)-based image processing electronics, PHOTONIS has achieved low-read noise imaging with enhanced signal-to-noise ratio at quarter moon illumination, all at standard video frame rates. The performance of this CIS is discussed herein and compared to other commercially available CMOS and CCD for long-range observation applications.

9100-4, Session 1

A 33-mpixel 120-fps CMOS image sensor using 0.11-μm CIS process *(Invited Paper)*

Toshio Yasue, Tetsuya Hayashida, Jun Yonai, Kazuya Kitamura, Japan Broadcasting Corp. (Japan); Toshihisa Watabe, NHK Engineering System, Inc. (Japan) and Shizuoka Univ. (Japan); Hiroshi Ootake, Hiroshi Shimamoto, NHK Japan Broadcasting Corp. (Japan); Tomohiko Kosugi, Takashi Watanabe, Satoshi Aoyama, Brookman Technology, Inc. (Japan); Shoji Kawahito, Shizuoka Univ. (Japan) and Brookman Technology, Inc. (Japan)

We have been researching and developing CMOS image sensor and camera to realize "Super Hi-Vision" (8K UHDTV system). Our image sensor has 2.8 μm x 2.8 μm pixel, 33-megapixel resolution (7680 horizontal pixel by 4320 vertical pixel), 120-fps frame rate and 12-bit tone reproduction. These parameters indicate that Super Hi-Vision image sensor has smaller pixel area and shorter exposure time, therefore the sensitivity is lower than HD image sensors used in broadcasting today. We tried to improve the sensor's sensitivity by using nanofabricated manufacturing process. It reduces the capacitance of FDA (floating diffusion amplifier) in the pixel, which also means the increase of the conversion gain of the FDA. As a result, the sensitivity of the sensor, which is proportional to the conversion gain, could be improved. This time, we used 0.11 μm CMOS image sensor process.

Prototyped image sensor exhibits the conversion gain of 110 μV/e- and sensitivity of 2.4 V/lx/s. The conversion gain is 1.8 times, and the sensitivity is 1.6 times higher than those of the conventional image sensor fabricated by 0.18 μm process [1]. Furthermore, our new sensor demonstrates the input referred random noise of 2.1 e-rms (measured at 120 fps and analog gain = 15), lower than conventional image sensor of 4.1 e-rms (measured at 120 fps and analog gain = 7.5)[1].

[1] K. Kitamura et al., "A 33-Megapixel 120-Frames-Per Second 2.5-Watt CMOS Image Sensor With Column-Parallel Two-Stage Cyclic Analog-to-Digital Converters," IEEE Trans. Electron. Devices, Vol. 59, no. 12, pp.3426-3433, Dec. 2012

9100-5, Session 2

Low-cost high-performance multispectral camera system for dual-use applications *(Invited Paper)*

Patrick Oduor, Genki Mizuno, Robert Olah, Achyut K. Dutta, Banpil

Photonics, Inc. (United States); Nibir K. Dhar, Defense Advanced Research Projects Agency (United States)

The extension of camera system sensitivity from the visible spectrum (VIS) into the infrared (SWIR) region has the potential to bring tremendous improvements and new capabilities to commercial and industrial imaging systems that are already standard in defense imaging applications. However, existing infrared imaging technologies are very expensive. At costs in the tens of thousands of dollars per camera, it is difficult to penetrate high-volume civilian application markets, let alone equip every warfighter with a high-performance SWaP-C imaging unit. Because of their complexity, cost, and low yield, SWIR cameras are confined primarily to selected military markets, severely curtailing their total addressable market. Despite continuing innovations in the quality and capabilities of SWIR cameras, widespread adoption for both defense and civilian applications will require significant cost reductions to become practical for both specialized and general use in military and commercial imaging systems, and perhaps even consumer applications in the future. Banpil Photonics has developed a low-cost high-performance multispectral camera system for VIS to SWIR imaging for the most demanding high-sensitivity and high-speed military, commercial and industrial applications. The 640x512 - pixel InGaAs 15μm uncooled camera system is designed to provide a compact, small-form factor to within a cubic inch, high sensitivity needing less than 100 electrons, high dynamic range exceeding 190 dB, high-frame rates greater than 1000 FPS at full resolution, and low power consumption below 1W. This is practically all the feature benefits highly desirable in military imaging applications to expand deployment to every warfighter, while also maintaining a low-cost structure demanded for scaling into commercial markets. This paper begins with a description of the features of the ROIC, an innovation integrating advanced digital electronics functionality, which has made the confluence of high-performance capabilities on the same imaging platform practical at low cost. It continues with a discussion of the strategies employed including in-house innovations of the key components (e.g. FPA) within our control while maintaining a fabless model, and strategic collaboration with partners to attain additional gains on optics, electronics, and packaging. We will highlight the challenges and potential opportunities for further cost reductions to achieve a goal of a sub-$1000 uncooled high-performance camera system. Finally, a brief overview of emerging military, commercial and industrial applications that will benefit from this high performance imaging system and their forecast cost structure will be presented.

9100-6, Session 2

Cots-based approach for lowering costs in high-performance infrared cameras *(Invited Paper)*

S. Raja Krishnamoorthi, Christopher Anton, Episensors, Inc. (United States)

Among the challenges facing the military is finding ways to reduce the cost of high performance, infrared cameras. This has not been an easy task because the components utilized in these cameras have been customized to specific applications, and the technologies themselves are very expensive. The result, however, is that such cameras are not deployed among warfighters to the maximum extent possible, thus diminishing the potential for the use of such technology.

Today, increasingly, private companies are being tasked with creating and implementing new strategies to approach the complex problem of cost reduction in such cameras. One strategy is to employ commercial off-the-shelf (COTS) technologies to do so. COTS components usually are produced en masse and are, therefore, more cost-effective than customized one-off piece parts. They have also been tested and subjected to greater field usage; therefore, they have usually evolved and improved with changing market demands. Thus, COTS components could enjoy greater innovation over the long term. That said, the COTS approach is fraught with its own unique challenges, and dealing with them is not always straightforward. Some amount of customization is required, especially in the camera core electronics and software, as well as the cooling components of the camera. In addition, collaboration is required with makers of these components in order to modify their components in different ways to mate or "talk" with components made by others. Still, the COTS approach holds great potential for reducing costs in camera systems.

Episensors, Inc. has been tasked by DARPA to create a COTS-based approach to lowering the cost of short wavelength infrared (SWIR) cameras. Collaborating with other companies, Episensors has developed an approach to employ COTS-based components for, among other things, optics, the camera core, cooling, packaging, and housing. Episensors has made progress on all these fronts, though work remains to realize the full potential of the COTS-based approach. The purpose of this presentation will be to explain Episensors's unique approach; illuminate the challenges that lay ahead with this approach; and discuss potential solutions to these challenges.

9100-7, Session 2

Advanced low cost uncooled thermal imaging camera development at Raytheon *(Invited Paper)*

Paolo Masini, Matthew Kuiken, Mark J. Lamb, Donald D. Chi, Matthew W. Brick, Raytheon Co. (United States)

Raytheon has been investigating methods for the reduction of Size, Weight, Power and Cost for uncooled LWIR based systems.

In this paper we will discuss the development for the DARPA LCTI-M program which is a major catalyst in providing a cost effective thermal imaging system to every war fighter. In this paper we will report on the progress to date in the development of a Low Cost thermal imaging camera system. This paper will describe the confluence of various technologies that enable a thermal imaging camera that has dramatically reduced cost, power and weight. We will, also, discuss the various technology elements for this thermal imaging system, including the developments of ultra small pixel pitch micro-bolometer arrays utilizing a commercial foundry, wafer scale packaging for an ultra small pixel pitch uncooled LWIR detector, heterogeneous die level integration of an electronics camera core engine, and very low cost infrared optics development. We will demonstrate this thermal imaging camera system comprised of the technology elements above in a Smartphone streaming live Uncooled LWIR imagery across a wireless network. An easy to use application running on the Smartphone will be used to control the thermal imaging camera and to demonstrate various image processing and image enhancement features useful for a variety of end use products.

Additionally, we will discuss the heart of the LCTI-M camera system, and how this camera core can be utilized for various dual-use applications for law enforcement, first responders, firefighting, and security and surveillance in addition to military products.

9100-8, Session 2

High-density interconnect bonding for 3d integrated imaging systems

Matthew Lueck, John M. Lannon Jr., Chris W. Gregory, Dean M. Malta, Alan Huffman, Dorota S. Temple, RTI International (United States)

3D integration of imaging arrays with readout integrated circuits has been shown to increase imaging capability while simultaneously decreasing device area and power consumption compared to analogous 2D designs. A key enabling technology for 3D integration is the use of high density metal-metal bonding to form pixel-level interconnects between device layers.

In this paper we review recent progress in high density, sub-10 μm pitch interconnect bonding for 3-D integration of imaging systems. Specifically, we will present results from successful demonstrations of the use and reliability of Cu-based microbumps for fine pitch interconnection of 640 x 512 arrays. InP and Si die have been bonded to Si substrates using an area array of Cu or alloyed Cu/Sn microbumps on 5 μm or 10 μm pitch. After bonding, the channel yield was used to estimate the operability of the 640 x 512 arrays to be greater than 99.99% for both InP-Si die pairs and Si-Si die pairs. We will also compare the reliability of as-bonded die pairs with die pairs that have been capillary underfilled.

9100-9, Session 2

In-plane carrier transport in InAs/InGaSb superlattices for VLWIR detectors

Hemendra Kala, Gilberto A. Umana-Membreno, The Univ. of Western Australia (Australia); Mikhail A. Patrashin, Iwao Hosako, Kouichi Akahane, National Institute of Information and Communications Technology (Japan); Jarek Antoszewski, Lorenzo Faraone, The Univ. of Western Australia (Australia)

InAs/(In)GaSb Type-II superlattices (SL) are an important material system for high-performance infrared radiation detectors, with performance levels that are predicted to rival those of HgCdTe. For applications in the very long wavelength infrared (VLWIR) region, InAs/(In)GaSb Type-II SL offer flexible tunability of their effective bandgap between 0-50meV, which is easier to achieve than in conventional HgCdTe-based detectors. There are however few report on the electronic properties of InAs/(In)GaSb SL designed for VLWIR radiation sensing.

In this work, we present results of a study of in-plane electronic transport in strained-layer InAs/InGaSb Type-II SL designed for VLWIR detection. The samples studied were grown by molecular beam epitaxy on GaSb substrates, and consisted of 500nm GaSb buffer layer, followed by 40 SL periods (4.21nm InAs/ 2.51nm In0.35Ga0.65Sb), and terminated with a 20 nm InAs cap layer.

In order to unambiguously discriminate the transport parameters of the SL region from those associated with the p-type GaSb substrate, magnetic field dependent Hall-effect measurements and high resolution mobility spectrum analysis were performed on the SL sample and on a representative GaSb substrate. This allowed identification of two hole carrier peaks in the GaSb substrate attributable to heavy and light holes with mobilities of 520cm2/Vs and 2,500cm2/Vs at 300K. While the contribution from substrate holes dominated the SL sample conductivity (representing over 90% of total conductivity at 300K), two electron species with mobilities of 15,600cm2/Vs and 8,200cm2/Vs were detected at 300K, which have been tentatively attributed to the 269nm SL region and the 20nm InAs cap layer, respectively.

9100-10, Session 2

InAsSb detector and FPA data and analysis *(Invited Paper)*

Arvind I. D'Souza, DRS Sensors & Targeting Systems, Inc. (United States)

InAsSb material with a cutoff wavelength in the 5 μm range has been grown on GaAs substrates. The MWIR InAsSb detector arrays were fabricated and hybridized to fanouts and ROICs to permit measurement of the electrical and optical properties of detectors. Variable temperature Jdark vs Vd measurements have been made with the dark current density ~ 10-5 A/cm2 at 150 K. The external QE measured using a narrow band filter centered at ~ 4 μm had values in the 65 – 70 % range. Since the detectors were illuminated through a GaAs substrate which has a reflectance of 29%, the internal QE is greater than 90 %. Additional response and noise measurements are being conducted and that data will also be presented. The noise measurements include long time series data which when Fourier transformed will provide detector noise as a function of frequency.

9100-11, Session 3

Materials for imaging acousto-optic tunable filters *(Invited Paper)*

Neelam Gupta, U.S. Army Research Lab. (United States)

Research and development of robust compact hyperspectral imagers that can acquire both spectral and spatial features from a scene of interest is of utmost importance for standoff detection of targets as well as chemical and biological agents and backgrounds. Hyperspectral imagers can acquire images with narrow spectral bands and take advantage of the characteristic spectral signatures of different materials making up the scene. At the Army Research Laboratory (ARL), we are developing hyperspectral imagers based on acousto-optic tunable filters (AOTFs) that can provide adaptive no-moving-parts imagers from the UV to the long wave infrared (LWIR) to acquire a two-dimensional spectral image and build up a two-dimensional image cube as a function of time instead of using traditional gratings or prisms based approach. Here, we will brief on the development of different imaging AOTFs operating from the UV to the LWIR based on a variety of birefringent materials and present highlights of the spectral imaging results obtained including those on broadband imaging. We will also discuss development of mercurous halide crystals that can be used to develop AOTFs operating over a wide spectral region.

9100-12, Session 3

Silicon nitride microphotonics for mid-infrared sensing applications

Pao T. Lin, Vivek Singh, Lionel C. Kimerling, Massachusetts Institute of Technology (United States); Dawn Tan, Singapore Univ. of Technology & Design (Singapore); Anuradha M. Agarwal, Massachusetts Institute of Technology (United States)

Integrated mid-infrared waveguides and directional couplers are demonstrated on silicon nitride (SiN) thin films by low-pressure chemical vapor deposition. The prepared SiN film has a broad spectral transparency from visible up to mid-infrared (mid-IR). The SiN waveguide shows a dominant fundamental mode with an optical loss less than 0.2 dB/cm at = 2.5 – 2.8 μm. In addition, we demonstrate an efficient SiN directional coupler with an high extinction ratio upon wavelength sweep between λ = 2.5 μm to λ = 2.7 μm. With the inherent advantage of complementary metal–oxide–semiconductor (CMOS) compatibility, our SiN platform paves the way to create sophisticated photonic circuits that are desired for chip-scale mid-IR biochemical sensors.

9100-13, Session 3

Enhanced light-matter interaction using plasmonic metamaterial structures for thin-film photodetector elements

Qiaoqiang Gan, Univ. at Buffalo (United States)

It is generally believed that minimizing the volume of active material helps to reduce the noise and thermal excess carriers in the diffusion-limited operating mode. An ultra-thin active layer is promising to enhance the speed performance of conventional photodetectors (PD) to surpass their commonly available high frequency cutoff. Unfortunately, due to the insufficient optical absorption of the ultra-thin active layers, the signal will be sacrificed simultaneously when thinner active layers are used in conventional PDs. Consequently, compact/miniaturized super absorber structures are highly desirable for future PDs for sensitive and high speed sensing/imaging applications, which, if successful, is critical to address the long-existing limitation between the speed and the responsivity for PDs and cameras. In this invited talk, we will summarize recent progress on developing thin-film improved PD devices, including nano-interdigitated electrode for high-speed UV metal-semiconductor-metal PDs [1] and recently developed strong interference effect in highly absorbing media [2,3] for ultra-thin film PD elements. The design principle of spectral tunability and optimization strategies of the absorption enhancement will be explained. Particularly, the ultra-thin film interference effect will be validated by preliminary experiment result using 2-3-nm-thick Ge film, demonstrating the potential of minimizing the thickness of the active layers. In addition, super absorptions using 10-20-nm-thick metal films will also be demonstrated to develop all-metal Schottky barrier [4] or metal-insulator-metal junction PDs [5].

[1] Plasmonics 8, 239 (2013).

[2] Nat. Mater. 12, 20 (2013).

[3] Nat. Mater. 12, 158 (2013).

[4] Science 332, 702 (2011).

[5] Adv. Mater. 25, 1301 (2013).

9100-14, Session 3

Miniaturized imaging spectrometer based on Fabry-Perot MOEMS filters and HgCdTe infrared focal plane arrays *(Invited Paper)*

Silviu Velicu, Jeremy D. Bergeson, Chris Buurma, EPIR Technologies, Inc. (United States); Tae Sung Kim, EPIR Technologies, Inc. (United States) and Univ. of California, Santa Cruz (United States); Joel Kubby, Univ. of California, Santa Cruz (United States); Neelam Gupta, U.S. Army Research Lab. (United States)

Imaging spectrometry can be utilized in the midwave infrared (MWIR) and long wave infrared (LWIR) bands to detect, identify and map complex chemical agents based on rotational and vibrational emission spectra. Hyperspectral datasets are typically obtained using grating or Fourier transform spectrometers to separate the incoming light into spectral bands. At present, these spectrometers are large, cumbersome, slow and expensive. Their resolution is limited by bulky mechanical components such as mirrors and gratings. Low-cost, miniaturized imaging spectrometers are of great interest. Microfabrication of micro-electro-mechanical-systems (MEMS)-based components opens the door for producing low-cost, reliable optical systems. We present here our work on developing a miniaturized IR imaging spectrometer by coupling a mercury cadmium telluride (HgCdTe)-based infrared focal plane array (FPA) with a MEMS-based Fabry-Perot filter (FPF). The two membranes are fabricated from silicon-on-insulator (SOI) wafers using bulk micromachining technology. The fixed membrane is a standard silicon membrane, fabricated using back etching processes. The movable membrane is implemented as an X-beam structure to improve mechanical stability. The geometries of the distributed Bragg reflector (DBR)-based tunable FPFs are modeled to achieve the desired spectral resolution and wavelength range. Additionally, acceptable fabrication tolerances are determined by modeling the spectral performance of the FPFs as a function of DBR surface roughness and membrane curvature. These fabrication non-idealities are then mitigated by developing an optimized DBR process flow yielding high-performance FPF cavities. Zinc Sulfide (ZnS) and Germanium (Ge) are chosen as the low and the high index materials, respectively, and are deposited using an electron beam process. To ensure high and uniform reflectance over the wavelength spectrum of interest (~ 8-11um), five stacks of Ge/ZnS layers are used to form the DBRs. Photoresist SU-8 is used to define the optical cavity between the two mirrors. FPF tuning is achieved with electrostatic actuation. The operation of the assembled filter device is demonstrated at room temperature. Further, FPAs suitable for integration with the MEMS filters have been fabricated on HgCdTe material. Imaging and radiometric characterization data will be presented.

9100-15, Session 3

Physiologic cardiovascular strain and intrinsic wave imaging *(Invited Paper)*

Elisa E. Konofagou, Columbia Univ. (United States)

Cardiovascular disease remains the primary killer worldwide. The heart, being essentially an electrically-driven mechanical pump, alters its mechanical and electrical properties to compensate for loss of normal mechanical and electrical function. The same adjustment is also performed in the vessels that constantly adapt their properties to accommodate mechanical and geometrical changes related to aging or disease. Consider a real-time, quantitative assessment of cardiac contractility, conduction and vascular function before the specialist can visually detect it. This new physiologic data could open up interactive therapy regimes that are currently not considered. The eventual goal of this technology is to become a specific method for estimating the position and severity of contraction defects in cardiac infarcts or angina, improving care and outcomes as well as detecting stiffness changes and overcoming the current global measurement limitations in the progression of vascular disease, at little more cost or risk than that of a clinical ultrasound.

9100-16, Session 4

A review on antimonide-based semiconductors for high-performance optoelectronic devices in center for quantum devices *(Keynote Presentation)*

Manijeh Razeghi, Northwestern Univ. (United States)

In recent years, the narrow-bandgap antimonide-based semiconductors are widely regarded as one of the strong candidate material systems for fabrication of the third generation of infrared imagers and integrated circuits with ultra-high speed and ultralow power consumption. Antimonide-based semiconductors mainly refer to the binary, ternary, and quaternary compound semiconductors, such as GaSb, InSb, AlSb,

InAsSb, InSbBi, InTlSb, and InTlAsSb. Furthermore, antimonide-based semiconductors can be used to form artificial quantum structures such as GaSb/InAs or InAs/AlSb/GaSb type-II superlattices.

Study of different antimonide-based semiconductors for infrared detection and emission applications has been an active field of research at Center for Quantum Devices (CQD) for more than two decades. These efforts cover almost all members of antimonide-based semiconductors family from simple binary compounds, such as InSb, to complicated quaternary ones like InTlAsSb. In the other hand, antimonidebased type-II superlattices have been subject of extensive studies at CQD. These studies resulted in demonstration of infrared photodetectors and imagers which can cover infrared spectrum from 1.5 to longer than 32 μm.

We are going to present a review of two decade antimonide-based semiconductors development for detection and imaging at different infrared regimes at CQD.

9100-17, Session 4

Case for small pixels: system perspective and FPA challenge *(Invited Paper)*

Jim Robinson, Michael A. Kinch, Michael J. Marquis, Duke Littlejohn, Kristina Jeppson, DRS RSTA, Inc. (United States)

In imaging systems, whether visible or infrared, the pixel dimension plays a crucial role in determining critical system attributes such as size, weight, and power (SWAP). Smaller pixels enhance the value proposition of the imager through reduced cost Focal Plane Arrays (FPAs) and/or added system functionality for a given spatial footprint. Ultimate pixel dimensions are

limited by diffraction effects from the aperture and are in turn wavelength dependent. Limits to the reduction in pixel dimensions will be explored and related to the historical trends in system design with accompanying performance attributes. Key challenges in realizing ultimate pixel dimensions in focal plane array design will be discussed. Progress toward these limits at DRS will be reviewed for both LWIR and MWIR HgCdTe Focal Plane arrays fabricated with 5 micron pixel dimensions. Possible system implications tied to the success of these shrinking pixel FPAs will be postulated.

9100-18, Session 4

Performance benefits of sub-diffraction sized pixels in imaging sensors *(Invited Paper)*

John T. Caulfield, Cyan Systems (United States)

Cyan has been improving designs of imaging systems using smaller sub diffraction sized pixels, and results show that smaller pixels result in a number of related systems benefits such as compact size and weight, smaller optics, improved IFOV and detection range, etc. Cyan has demonstrated that spatial oversampling can improve aliasing, sensitivity, and drive reductions in False Alarms through oversampled correlated processing. Oversampled IR sensors will also improve acuity in turbulent and hazy conditions over larger pixel IR focal plane array sensors.

We will show quantitative data to illustrate the improvements in resolution, NEP, detection range, and false alarm suppression of the oversampled IR sensor as the temporal and spatial oversampling are increased. We will explain the phenomena of reducing pixels size improving Noise Equivalent Power. We will show how smaller pixels have lower SNR, and how using temporal and spatial oversampling can compensate and effectively increase SNR lost with smaller pixels. We will quantify the limits of performance of Oversampling based on theory, and also with simulated imagery using realistic parameters such as shot noise and thermal noise using a Monte Carlo type analysis. We will review in detail the results of the Monte Carlo modeling of Oversampling FPA. We will derive and demonstrate the theoretical limits of both temporal and spatial oversampling using both On and Off Focal Plane processing that is required to realize good performance.

9100-19, Session 4

Effect of dense planer focal plane array on device performances

Chieh-Ting Lin, Robert Olah, Achyut K. Dutta, Banpil Photonics, Inc. (United States); Nibir K. Dhar, Defense Advanced Research Projects Agency (United States)

As the technologies in focal plane array (FPA) progresses, the industry is pushing for smaller pixel size and spacing between the pixels. The reduction in pixel size and spacing will increase both the resolution and fill factor which reduces the cost and increases the performance. However, as the density of the array elements increases, the crosstalk between the nearest neighboring pixels become a significant issue. Here we examine the case for a planer FPA with epitaxially grown NIN+ structure and the planer junctions are formed by diffusing P-type dopant into the N doped layer. We first examine the possible spacing by considering the lateral depletion region width to set the upper boundary for the spacing. The depletion region width is calculated by solving Poisson's equation for Gaussian doping profile and the isolation of adjacent pixel is dependent on the formation of the back to back diodes to block the current flowing towards the device. Therefore overlap of the depletion regions indicates shorting and sets the minimum possible spacing. The electrical and optical crosstalks are modeled by using a DC resistive model to gauge the effect of current flow as the spacing reduces. Series of device arrays with various device pitches and device sizes ranging from 7 μm to 15 μm with device pitch from 7.5 μm to 18 μm are fabricated and tested under both dark and illumination conditions for their electrical performances including the crosstalk. The simulated and measured results will be presented.

9100-20, Session 4

Enabling more capability within smaller pixels: advanced wafer-level process technologies for integration of FPAs with readout electronics *(Invited Paper)*

Dorota S. Temple, Erik Vick, Matthew Lueck, Dean M. Malta, John M. Lannon Jr., RTI International (United States)

Two key trends in the development of infrared focal plane arrays (FPAs) over the last decade are the decreasing pixel size and the increasing signal processing capability at the device/component level. The former leads to the increased information content within the same FPA die size. The latter will ultimately result in the sensor behaving like a smart-system peripheral rather than a passive component—with complex functions like calibration, compensation and self-testing being executed on, rather than off, the chip. This added flexibility could greatly enhance the sensor performance, increase its stability and reliability, and reduce the size, weight, power and cost of the overall system.

Enabling more capability within smaller pixels requires the use of advanced wafer-level processes for the integration of the FPAs with silicon readout integrated circuits (ROICs). In this paper we will review the development of these technologies, starting with high density face-to-face integration of FPAs with Si ROICs, and proceeding to approaches in which the infrared sensor is integrated with three-dimensional ROIC stacks composed of multiple layers of Si circuitry interconnected using metal-filled through-silicon vias. We will present examples from functional demonstrations of these technologies. We will also describe the roadmap for the continued development of the integration technology for increasingly smaller and smarter pixels, and identify development needs that have to be met to transition research results to system-level applications.

9100-21, Session 4

Direct optimization and solution space visualization of wafer-level manufactured LWIR systems for maximized detection range and minimized SWAP-C *(Invited Paper)*

Kenneth S. Kubala, Robert M. Bates, FiveFocal LLC (United States)

The typical approach for the design of optical systems involves the largely independent design of the components (lens, sensor, algorithms, display) with a system engineer providing the intermediary framework for trading margin between the components. As the system has more and more complexity, and as there are more system level metrics that go beyond detection range metrics such as SWAP-C, the "manual" system level optimization is very unlikely to yield optimal solutions.

Through the development of system simulation and optimization software that incorporates the optical lens model with the target, sensor, signal processing, display, and observer models and their associated design degrees of freedom, the end-to-end performance of the system can be optimized directly according to the probability of task performance using the standard targeting task performance (TTP) metric along with SWAP-C metrics.

As an example of the process, an uncooled LWIR camera system is design using a wafer-level optics architecture where the weighting and targets for performance and SWAP-C are varied resulting in many solutions that map out the solution space. The results are visualized in custom software that allows the user to filter the solutions based on any of the system level or component metrics allowing comparison of cost vs. performance vs. size vs. weight vs. power vs. frame rate of an LWIR wafer level optical solution. The presented visualization software provides a common framework for both technical and non-technical users to explore the tradeoffs and ultimately select the solution that is best for a specific application.

9100-22, Session 4

Nanostructured detector technologies for optical sensing applications *(Invited Paper)*

Ashok K. Sood, Magnolia Optical Technologies, Inc. (United States); Roger E. Welser, Magnolia Solar, Inc. (United States); Nibir K. Dhar, Defense Advanced Research Projects Agency (United States); Dennis L. Polla, Univ. of Minnesota-Twin Cities (United States); Madan Dubey, Priyalal S. Wijewarnasuriya, U.S. Army Research Lab. (United States)

Optical sensing technology is critical for optical communication, defense and security applications. Advances in optoelectronics materials in the UV, Visible and Infrared, using nanostructures, and use of novel materials such as CNT and Graphene have opened doors for new approaches to apply device design methodology that are expected to offer enhanced performance and low cost optical sensors in a wide range of applications.

This paper is intended to review recent advancements and present different device architectures and analysis. The chapter will briefly introduce the basics of UV, Visible and Infrared detection physics and various wave bands of interest and their characteristics.

We will cover the UV band (200-400 nm) and address some of the recent advances in nanostructures growth and characterization using GaN/AlGaN, ZnO/MgZnO based technologies and their applications. We will also discuss nanostructure based Si/SiGe technologies (400-1700 nm) that will cover various bands of interest in visible-near infrared for detection and optical communication applications. The chapter will also discuss some of the theoretical and experimental results in these detector technologies.

Recent advancements in design and development of CNT and Graphene based detection technologies have shown promise for optical sensor applications. We will present theoretical and experimental results on these device and their potential applications in various bands of interest.

9100-23, Session Posters-Thursday

Applications of the Lambert W function to analyze digital camera sensors

Daniel Villegas, Univ. EAFIT (Colombia)

The Lambert W function is applied via Maple to analyze the operation of the modern digital camera sensors. The Lambert W function had been applied previously to understand the functioning of diodes and solar cells. The parallelism between the physics of solar cells and digital camera sensors will be exploited. Digital camera sensors use p-n photodiodes and such photodiodes can be studied using the Lambert W function. At general, the bulk transformation of light into photocurrent is described by an equivalent circuit which determines a dynamical equation to be solved using the Lambert W function. Specifically, in a camera senor, the precise measurement of light intensity by filtering through color filters, is able to create a measurable photocurrent that is proportional to image point intensity; and such photocurrent is given in terms of the Lambert W function. It is claimed that the drift between neighboring photocells at long wavelengths affects the ability to resolve an image and such drift can be represented effectively using the Lambert W function. Also is conjectured that the recombination of charge carries in the digital sensors is connected to the notion of “noise” in photography and such “noise” could be described by certain combinations of Lambert W functions. Finally, it is suggested that the notion of bias, and varying the width of the depletion zone, has a relationship to the ISO “sped· of the camera sensor; and such relationship could be described using Lambert W functions.

9100-24, Session Posters-Thursday

Application of the Ornstein- Uhlebeck equations for biomedical image processing

Juan P. Mesa Lopez, Univ. EAFIT (Colombia)

The purpose of this paper is to demonstrate the implementation of a new kind of image filter, in which the equations of the Ornstein-Uhlenbeck process are used in image processing in order to detect the edges of computerized images taken with magnetic resonance imaging (MRI) scanners, as a generalization of the standard Gaussian filter.

This new filter will be called Ornstein-Uhlenbeck filter (OUF). One of the results obtained after applying the filter to the image, with the variation of the parameter σ is an effective differentiation of the various organs that are next to each other in each one of the resulting images. In addition, the edges of the internal body parts and organs are highlighted efficiently and differentiated from their surroundings.

9100-25, Session Posters-Thursday

Improvements to quality of mass produced sapphire

John P. Ciraldo, Rubicon Technology Inc. (United States)

High quality sapphire demonstrates properties that are of great interest to a wide range of industrial and academic applications. For example, relatively flat transmission across a wide range of wavelengths makes sapphire very useful in optical applications. As one of the hardest material in nature, sapphire is also quite useful in applications where resistance to chemical decomposition, radiation damage, and mechanical wear are important concerns. However, the limitations in material quality have prevented adoption of sapphire material into some particularly sensitive applications. In this talk I will demonstrate advances that Rubicon Technology has made in sapphire quality that far exceed what is currently available through other manufacturers. Improvements to growth process, as well as increased control over supply material have allowed Rubicon to consistently grow sapphire demonstrating rocking curves with FWHM values less than 9 arc-seconds, as verified by Argonne National Laboratory. Etch pit density and x-ray topography results verify near defect free crystals. Optical characterizations confirm transmission near or at maximum theoretical values. Comparison to other industry leaders will provide further confirmation that Rubicon is currently creating material that is of significantly better quality that what is currently available elsewhere. The dramatic improvements in crystal quality achieved by Rubicon are already allowing sapphire produced by Rubicon to be used in sensor technologies where sapphire was previously unusable due to high defects.

9100-26, Session Posters-Thursday

Geometric superresolution by using a two-dimensional orthogonal encoding mask

Yangyang Liu, Bin Xiangli, Qunbo Lv, Min Huang, Jinsong Zhou, Linlin Pei, Dandan Zhang, Academy of Opto-Electronics (China)

In many modern optical systems, the resolution is limited not only by the diffraction caused by physical dimensions of the optics lens, but by the CCD’s nonzero pixel size,especially for the traditional incoherent illumination, the restriction of CCD pixel is greater than that of optical diffraction. Here we develop a novel approach to enhancing resolution beyond the limit set by CCD’s pixels, in which a two-dimensional and orthogonal encoding mask is attached before the imaging lens to modulate frequency on input target spectrum.

Here we focus on the design about a 4-f optical imaging system, considering the ability of Fourier transformation to achieve the equivalent conversion between space and frequency domain. And to prevent the loss

of frequency in the overlapping regions when sampled by a classical CCD, there must be some proportion between the spatial range of object plane and corresponding frequency plane. Meanwhile, the wavefront aberration of Fourier lens needs to be controlled to fulfill the mathematical features of Fourier transformation.

We apply to improving and revising the theoretical design for the encoding mask based on the design limit of optical-mechanical engineering, and we analyze the different orthogonal forms of encoding masks which can bring the spectra diffraction to the imaging area. In this scheme, we calculate and discuss the total dimension, formation and element dimension of the encoding mask, to ensure compliance with all the optical wavelengths of project indicator. Furthermore, we consider the spectrum message based on the zero level to the second diffraction, and finally achieve the spectrum data matched to the original input object after mathematical process.

According to the theoretical discussion, revision and algorithm simulation, the results in the preliminary testing system show that the encoding mask can be used to produce enhancement of resolution by a factor of 2 in exchange for decreasing the field of view by the same factor.

9100-27, Session Posters-Thursday

Design of p-on-N+ HgCdTe heterojunction photodiodes on Si substrate

Peng Zhang, Zhenhua Ye, Shanghai Institute of Technical Physics (China)

The application of HgCdTe-on-Si material is very attractive in IRFPA technology, because of lower cost and consistent thermal coefficient of expansion with Si ROIC. However, interface recombination between HgCdTe active region and buffer layer on Si substrate makes it difficult to manufacture high quantum efficiency LW IRFPAs detectors.

In the application of the LW IRFPAs detectors, narrow-band of spectral response is extensively utilized to improve the detectivity of desired wavelength-band. Normally, p+-on-n or n+-on-p HgCdTe IRFPAs detectors are adopted to acquire the narrow-band, using the optical filter. In this paper, the Hg1-xCdxTe (x=0.21) LW IRFPAs detector adopts a new p-on-N+ structure grown by MBE on Si substrate. The bottom N-type window layer with high composition and heavy doping concentration can reduce the influence of surface recombination on the performance of the device. And compared with adding the optical filter, it is feasible to adjust the composition of the N-type layer to modify the cut-on wavelength of devices. Furthermore, due to the high absorption coefficient of the HgCdTe material, the incoming LW radiation is mainly absorbed within a thin absorption region. In the device, the thin region locating on the p-N+ junction will lead to higher quantum efficiency. On the other hand, the smaller bulk resistance of the heavily doped N-type layer ensures the uniformity of the pixel series resistance in the large format IRFPAs.

The quantum efficiency and the current-voltage characteristics of devices have been numerically simulated, using Crosslight TCAD software. Simulation results indicate that in contrast to the n+-on-p IRFPAs detector, the quantum efficiency of the p-on-N+ IRFPAs detector increased by 8.38%.

9100-28, Session Posters-Thursday

New approach for underwater imaging and processing

Yanan Wen, Weijian Tian, Bing Zheng, Guozun Zhou, Hui Dong, Qiong Wu, Qingdao Academy for Opto-Electronics Engineering (China)

In this paper, a new approach is presented to get a clear underwater image. Firstly, an inhomogeneous illumination method is developed to get the clear original image. Normal illumination system and inhomogeneous illumination system are used to capture the image in same distance. The result shows that the contrast and definition of processed image is greatly improved by inhomogeneous illumination method. Secondly, based on the theory of photon transmitted in the water and the particularity of underwater target detecting, the characters of laser scattering on underwater target surface and spatial and temporal characters of oceanic optical channel have been studied. Based on the Monte Carlo or time domain broadening simulation , how the water quality and other systemic parameters affect the underwater light transmission at spatial and temporal region has been studied, which provides the theoretical sustentation of enhancing the SNR and operational distance.

9100-29, Session Posters-Thursday

Analysis and simulation of a new kind of noise at the input stage of readout integrated circuit

Zhangcheng Huang, Yu Chen, Songlei Huang, Jiaxiong Fang, Shanghai Institute of Technical Physics (China)

Noise is a primary characteristics of an infrared focal plane array (FPA) that contribute to detection performance at low light level. In a capacitive-feedback trans-impedance amplifier (CTIA)-based readout integrated circuit (ROIC), reset noise can be removed by correlated double sampling (CDS). There is an exotic experimental phenomenon that FPA noise will increase greatly if the first sampling time of CDS is less than a specific value. A noise model at the input stage of ROIC is presented in this paper which explains that this new kind of noise is originated from incompletely settling of CTIA preamplifier. As this noise is performed in time domains, we use transient noise simulation technique to describe the dependence of this noise on detector pixel capacitance, integration capacitor, and some other design parameters. Based on the theoretical model analysis and simulation results, an effective design effort is obtained to reduce this kind of noise.

9100-30, Session Posters-Thursday

Responsivity performance of extended wavelength InGaAs shortwave infrared detector arrays

Tao Li, Xue Li, Xiumei Shao, Heng-Jing Tang, Haimei Gong, Shanghai Institute of Technical Physics (China)

InxGa1-xAs ternary compound is suitable for detector applications in the shortwave infrared (1-3 μm) band. The alloy In0.53Ga0.47As is lattice-matched to InP substrate and has a wavelength response between 0.9 μm to 1.7 μm. The increase of indium composition can extend the wavelength response to 2.6 μm (x=0.83). Compared to the In0.53Ga0.47As detectors, the dark current of In0.83Ga0.17As detectors is remarkably increased due to the lattice mismatch between InGaAs layer with high indium content and the InP substrate, and the responsivity of the In0.83Ga0.17As detectors drops sharply. These degradations restrict its using in low level application. In this paper, we reported on mesa type and planar type extended wavelength InGaAs detector arrays. The mesa type detectors were fabricated by mesa etching, side-wall and surface passivating processes based on p-i-n InAlAs/In0.83Ga0.17As/InxAl1-xAs/InP epitaxial structure, while the planar type detectors were fabricated by planar diffusion and surface passivating processes based on n-i-n InAlAs/In0.83Ga0.17As/InxAl1-xAs/InP epitaxial structure. The blackbody responsivities (Rbb) of these detectors at different temperatures were measured. The results showed that the Rbb of planar type detectors were much higher than the mesa type's. The laser beam induced current (LBIC) method was used to investigated the photoresponse of photo-sensitive area, and the sharply decreased photoresponse curve at the edge of the photo-sensitive area indicated a shorter hole diffusion length of the mesa type detector. This was mostly because the surface recombination reduced minority-carrier lifetime and the output photo current. When using an improved mesa-type process on the passivating technique, the response performance of the mesa detector was highly upgraded and comparable to the planar type's.

9100-31, Session Posters-Thursday

A revolutionary solution for shipping container identification and management

James Morrison, Jonathan Williams, Robert Fish, McQ, Inc. (United States)

Shipping containers are used by the US government to transport a variety goods throughout the world, yet there is no means to track them, which results in detention fees levied to the government, and no practical way to locate a given container. McQ has developed an automated system to provide accountability of US government owned containers entering or leaving a checkpoint, based on self powered, detection, and imaging system. This system uses McQ's rScene® micro radar to maintain a low power state until an approaching truck or train carrying the container is detected, which then enables video capture of the container. Once a video clip has been captured, McQ performs sophisticated image processing to optically locate the ISO identification code on the container, and perform an extensive set of preprocessing steps to prepare the text to input into a COTS optical character recognition (OCR) engine. The output of the system are automatically captured ISO codes, which are georeferenced by the fielded system, which can be used by the US government to track shipping containers in a variety of deployment scenarios including permanent facilities and road side disaster relief temporary installations. The system is easy to setup and operate. The system design as well as system performance based on field testing with shipping containers will be presented.

9100-32, Session Posters-Thursday

Quality assessment of pan-sharpened color image in comparison with 1-chip Bayer filter color and 3-chip color images in various lighting conditions

Sina Adhamkhiabani, Yun Zhang, Univ. of New Brunswick (Canada)

UNB pan-sharp method demonstrated its ability in producing high resolution color images using a pair of high resolution panchromatic and low resolution multispectral (Color) satellite imagery. Extensive research on the security camera systems shows that the concept could be utilized on the earth and for various kinds of imaging and monitoring cameras. Nowadays, 1-chip (Bayer filter cameras) and 3-chip cameras are widely used to produce color images and videos. These cameras have solid performance in high and normal lighting conditions. However in low lighting conditions, due to the received energy limitations in narrow spectral bands, the color images turn noisy and less sensitive. Moreover, due to the characteristics of the Bayer filters (in 1-chip cameras) and splitters (in 3-chip cameras) color distortions are obvious especially on the edges. Furthermore, the quality of color rendering in these images decrease in lower lighting conditions. On the other hand, the carried out research proved that by a pan-sharpening strategy, high resolution color images could be produced with less noise, smoother edges and better color rendering in comparison with a 1-chip camera system and under the same lighting conditions. In this paper, different imaging instances were produced under various lighting conditions will be demonstrated. Moreover, various assessments on the results will be noted.

9100-33, Session Posters-Thursday

Influence of pixel size and bit depth of the low resolution color image on the quality of pan-sharpened imagery: a case study with security video image frames

Sina Adhamkhiabani, Yun Zhang, Univ. of New Brunswick (Canada)

UNB Pan-sharp is a technique to produce high resolution color satellite imagery or security camera video frame by fusing a high resolution panchromatic image and a low resolution color image. Beside a competitive quality in comparison with the original high resolution color images, pan-sharpening can also decrease the lossless data rate to 50 percent of the original high resolution color image. As the spatial and radiometric resolutions of the panchromatic image plays a key role in the quality of pan-sharpened image, changes in the bit-rate and sampling pixel size of the low resolution color image frame will be a key for lossless compression. Using a fixed high resolution panchromatic image and various low resolution color images in different spatial and radiometric resolutions, in this paper, the quality of derived UNB-pansharpened images have been assessed. This study has been repeated for a few more sets of images in different lighting conditions. The main purpose of this study was to find the lowest bit-rate and sampling size for low resolution color images which keeps the quality of resulting pan-sharpened image. Original high resolution color images are also used as a reference for the quality control.

9100-34, Session Posters-Thursday

High-resolution unified touch screen for sensing capacitive touches and reading fingerprints

Pranav N. Koundinya, Sandhya Theril, Tao Feng, Weidong Shi, Univ. of Houston (United States)

With the increase in the number of smart devices such as smartphones and tablets, the need to secure the information they carry has become vitally important. Authentication is a vital part of security--it is not limited to gaining access to a physical hardware, it is extended to identifying and mapping the user to certain sensitive information (Pass codes for financial institutions, web portals and online services such as email and social networks). Traditional Password schemes such as number pass-code, pattern unlocking, facial recognition and others are very complicated, time consuming and requires users to pause their current activity to provide authentication. An alternative technique that alleviates these problems needs to be designed. Fingerprints have served in its fullest capacity in establishing a unique user identify over the course of time. Both fingerprints and touch sensing can be detected using the capacitive sensing technique. This paper presents a unique single device that is capable of sensing touch gestures and fingerprint. A high resolution transparent touch sensitive device and a novel read out circuit is discussed that drives the capacitive sensor array for touch interactions in low resolution and for fingerprint sensing in high resolution. Using circuit simulation and custom Verilog-A model for a transparent thin-film transistor, we show that our device can sense fingerprint in 8.25ms and detect capacitive touches in 0.6ms with an efficient power consumption of 1mW. These results imply that such a device is very much realizable and serve as an alternative means of authentication. Utilizing such a device a user independent authentication can be established which potentially makes passwords irrelevant. Furthermore, from a user's perspective, the introduced device is essential as it provides user transparent authentication that does not require any additional effort from the user.

9100-35, Session Posters-Thursday

Technology and application trends in IR photodetectors

Thierry Robin, TEMATYS (France)

The aim of our work is to identify the trends and challenges in the next years for infrared imaging photodetectors with a focus on commercially available FPA technologies: HgCdTe, InSb, QWIP, InGaAs and T2 SLS (Type II Strained Layer Superlattice). Most of these detectors are cooled, especially in MWIR and LWIR bands, and the military market remains the main market for cooled IR sensors and cameras. But the continuing decline in defense spending in many countries as well as the improved performance of uncooled detectors require manufacturers of cooled sensors to intensify

efforts: to improve performances while reducing cost and device size, weight and power (SWaP), to expand IR imaging applications for users in the military, homeland security as well as in commercial and industrial fields and also to provide added functionalities for advanced applications such as multiband, multicolor, active imaging and integrated optics. In-depth analysis of applications is provided, along with a description of the main players and the last market evolutions and future trends. We summarize our final data and analysis: market application segments and opportunities in SWIR, MWIR and LWIR, analysis of the trends and main challenges to be addressed both on technology side and application side in the next years. These data can be useful for scientists and manufacturers in the infrared sector but can also provide cross-fertilization towards other areas.

9100-36, Session Posters-Thursday

Performance of near-infrared InGaAs focal plane array with different series resistances to p-InP layer

Xiumei Shao, Xue Li, Tao Li, Zhangcheng Huang, Yu Chen, Heng-Jing Tang, Haimei Gong, Shanghai Institute of Technical Physics (China)

A planar-type InGaAs linear detector was designed and fabricated based on n-i-nx type InP/In0.53Ga0.47As/InP epitaxial materials. The major process of the detector contains planar diffusion, surface passivation, metal contact and annealing. The I-V curves and the relative spectral response were measured at room temperature. The relative spectral response is in the range of 0.9m to 1.7m. The R0A of the detector is about 2x106 Ω·cm^2 and the dark current density is 5~10nA/cm2 at -10mV bias voltage. The linear detectors were wire-bonded with readout circuits (ROIC) to form focal plane array (FPA). The input stage of the ROIC is based on capacitive-feedback transimpedance amplifier (CTIA) with a capacitor (Cint) to be 0.1pF. The FPAs were tested under different conditions. However, the signals are vibrating especially when they are close to the saturation voltage of the ROIC. The ohmic contact on p-InP region plays an important role in the performance of detectors and FPAs. In this case, the series resistance to p-InP layer of each pixel is up to 1x106Ω. The FPAs were simulated in case of InGaAs detectors with different series resistances. According to the simulation results, the signals of the FPAs will vibrate when the series resistances are beyond 4x104Ω. Then, the annealing temperature of the detectors was studied and the series resistances were lower than 1x104Ω. The optimized InGaAs linear detectors were wire-bonded with the same ROIC. The vibration of the signals disappears and the FPA shows good stability.

9100-57, Session Posters-Thursday

Wide dynamic range and high-sensitivity CMOS active pixel sensor using output voltage feedback structure

Sung-Hyun Jo, Myunghan Bae, Jang-Kyoo Shin, Kyungpook National Univ. (Korea, Republic of)

Recent commercial CMOS image sensors (CISs) require the high-sensitivity and wide dynamic range performance. Some equipments for high-sensitivity applications use photomultiplier tubes or charge-coupled devices. However, these photodetectors consume a large amount of power and cannot be integrated with CMOS circuits. Also, their sensors have narrow dynamic range due to high-sensitivity. For this reason, several approaches to improve both the sensitivity and dynamic range are being researched. This paper presents a wide dynamic range and high-sensitivity complementary metal oxide semiconductor (CMOS) active pixel sensor (APS) using output voltage feedback structure. The proposed APS has a high-sensitivity gate/body-tied (GBT) photodetector with an overlapping control gate that makes it possible to control the sensitivity of the proposed APS. The floating gate of the GBT photodetector is connected to the n-well and the overlapping control gate is placed on top of the floating gate for varying the sensitivity of the proposed APS. Dynamic range of the proposed APS is significantly increased due to the output voltage feedback structure. Maximum sensitivity of the proposed APS is 50 V/lux•s in the low illumination range and dynamic range is greater than 110 dB. The proposed sensor has been fabricated by using 0.35 μm 2-poly 4-metal standard CMOS process and its characteristics have been evaluated.

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9101-1, Session 1

Development, characterization, and application of compact spectrometers based on MEMS devices with in plane capacitive drives *(Invited Paper)*

Andreas Kenda, Martin Kraft, Werner Scherf, Carinthian Tech Research AG (Austria); Thilo Sandner, Harald Schenk, Fraunhofer-Institut für Photonische Mikrosysteme (Germany); Stephan Luettjohann, Bruker Optik GmbH (Germany)

With a trend towards the use of spectroscopic systems in various fields of science and industry, there is an increasing demand for compact spectrometers. For UV/VIS to the shortwave near-infrared spectral range, compact hand-held polychromator type devices are widely used and have replaced larger conventional instruments in many applications. Still, for longer wavelengths this type of compact spectrometers is lacking suitable and affordable detector arrays. In perennial development Carinthian Tech Research AG together with the Fraunhofer Institute for Photonic Microsystems endeavor to close this gap by developing spectrometer systems based on photonic MEMS. Here, we review on two different spectrometer developments, a scanning grating spectrometer working in the NIR and a FT-spectrometer accessing the mid-IR range up to 14μm. Both systems are using photonic MEMS devices actuated by in plane comb drive structures. This principle allows for high mechanical amplitudes at low driving voltages but results in gratings respectively mirrors oscillating harmonically. Both systems feature special MEMS structures as well as aspects in terms of system integration which shall tease out the best possible overall performance on the basis of this technology. However, the advantages of MEMS as enabling technology for high scanning speed, miniaturization, energy efficiency, etc. are pointed out. Whereas the scanning grating spectrometer has already evolved to a product for the point of sale analysis of traditional Chinese medicine products, the purpose of the FT-spectrometer as presented is to demonstrate what is achievable in terms of performance. Current developments topics address MEMS packaging issues towards long term stability, further miniaturization and usability.

9101-2, Session 1

Fourier transform infrared phase shift cavity ring down spectrometer

Elizabeth C. Schundler, James R. Engel, David J. Mansur, Robert Vaillancourt, Ryan Benedict-Gill, Scott P. Newbry, OPTRA, Inc. (United States)

OPTRA has developed a Fourier transform infrared phase shift cavity ring down spectrometer (FTIR-PS-CRDS) system under a U.S. EPA SBIR contract. This system uses the inherent wavelength-dependent modulation imposed by the FTIR on a broadband thermal source for the phase shift measurement. This spectrally-dependent phase shift is proportional to the spectrally-dependent ring down time. The spectral dependence of both of these values is introduced by the losses of the cavity including those due to the molecular absorption of the sample. OPTRA's approach allows broadband detection of chemicals across the feature-rich fingerprint region of the long-wave infrared. This represents a broadband and spectral range enhancement to conventional CRDS which is typically done at a single wavelength in the near IR; at the same time the approach is a sensitivity enhancement to traditional FTIR, owing to the long effective path of the resonant cavity. In previous papers, OPTRA has presented a breadboard system aimed at demonstrating the feasibility of the approach and a prototype design implementing performance enhancements based on the results of breadboard testing. In this final paper in the series, we will present test results illustrating the realized performance of the fully assembled and integrated breadboard, thereby demonstrating the utility of the approach.

9101-3, Session 1

Multiple-order staircase etalon spectroscopy

Michael K. Yetzbacher, Christopher W. Miller, Drew J. Boudreau, Marc Christophersen, Michael J. DePrenger, U.S. Naval Research Lab. (United States)

Traditional Fabry-Perot (FP) spectroscopy is bandwidth limited to avoid mixing signals from different transmission orders of the interferometer. Unlike Fourier transformation, the extraction of spectra from multiple-order interferograms resulting from multiplexed optical signals is in general an ill-posed problem. Using a Fourier transform approach, we derive a generalized Nyquist limit appropriate to signal recovery from FP interferograms. This result is used to derive a set of design rules giving the usable wavelength range and spectral resolution of FP interferometers or etalon arrays given a set of accessible physical parameters. Numerical simulations verify the utility of these design rules for moderate resolution spectroscopy with bandwidths limited by the detector spectral response. Stable and accurate spectral recovery over more than one octave is accomplished by simple matrix multiplication of the interferogram. In analogy to recently developed single-order micro-etalon arrays (Proc. of SPIE v.8266, no. 82660Q), we introduce Multiple-Order Staircase Etalon Spectroscopy (MOSES), in which micro-arrays of multiple order etalons can be bonded to or co-fabricated with a sensor array. MOSES enables broader bandwidth multispectral and hyperspectral instruments than single-order etalon arrays while keeping a physical footprint insignificantly different from that of the detection array.

9101-4, Session 1

On-chip random spectrometer

Brandon Redding, Seng-Fatt Liew, Raktim Sarma, Hui Cao, Yale Univ. (United States)

Spectrometers are widely used tools in chemical and biological sensing, material analysis, and light source characterization. The development of a high-resolution on-chip spectrometer could enable compact, low-cost spectroscopy for portable sensing as well as increasing lab-on-a-chip functionality. However, the spectral resolution of traditional grating-based spectrometers scales with the optical pathlength, which translates to the linear dimension or footprint of the system, which is limited on-chip. In this work, we utilize multiple scattering in a random photonic structure fabricated on a silicon chip to fold the optical path, making the effective pathlength much longer than the linear dimension of the system and enabling high spectral resolution with a small footprint. Of course, the random spectrometer also requires a different operating paradigm, since different wavelengths are not spatially separated by the random structure, as they would be by a grating. Instead, light transmitted through the random structure produces a wavelength-dependent speckle pattern which can be used as a fingerprint to identify the input spectra after calibration. In practice, these wavelength-dependent speckle patterns are experimentally measured and stored in a transmission matrix, which describes the spectral-to-spatial mapping of the spectrometer. After calibrating the transmission matrix, an arbitrary input spectrum can be reconstructed from its speckle pattern. We achieved sub-nm resolution with 25 nm bandwidth at a wavelength of 1500 nm using a scattering medium with largest dimension of merely 50 μm.

9101-5, Session 1

Overview of microplasmas-on-chips: from fundamentals to applications

Karthik Kommera, Vassili Karanassios, Univ. of Waterloo (Canada)

In recent years, low-power (e.g., ~10 Watt), atmospheric-pressure microplasmas (e.g., those with one critical dimension <1000 μm) have been receiving increasing attention in conferences and in the scientific and engineering literature. Although a variety of geometric designs and electrical powering schemes (e.g., dc, ac, rf, microwave, microplasmas with one electrode in contact with a solution) have been described in the literature, those developed on-chips will be the focus of this presentation. Such hybrid chips have been either rapidly-prototyped or 3d-printed. To provide a reference point for scale, 3d-printed microplasmas the size of a sugar cube were developed and used.

Unlike their atmospheric-pressure, larger size siblings that are 6000-10000 K hot, microplasmas are cold plasmas (e.g., they feel warm to the touch). Thus, they could be rapidly prototyped (e.g., by 3d-printing) on plastic substrates. In this presentation, fundamentals and some applications of microplasmas will be described and future research directions will be outlined.

9101-6, Session 1

Infrared molecular binding spectroscopy realized in sorbent coated microfabricated devices

R. Andrew McGill, Todd H. Stievater, Marcel W. Pruessner, U.S. Naval Research Lab. (United States); Scott A. Holmstrom, The Univ. of Tulsa (United States); Rachel C. McGill, Viet Q. Nguyen, Doewon Park, Christopher A. Kendziora, Robert Furstenberg, U.S. Naval Research Lab. (United States)

Sorbent materials are utilized in a range of analytical applications including preconcentrator coatings, chromatography stationary phases, and as thin films coatings deposited on transducers to concentrate analyte molecules of interest for detection. In this work we emphasize the use of sorbent materials to target absorption of a solubility class of analyte vapor and optically probe its interaction with infrared light. This allows us to take advantage of spectral changes, during specific molecular binding of a vapor to a target site in a sorbent, to aid in analyte detection. In this work a custom hydrogen-bond (HB) acidic sorbent with pendant hexafluoroisopropanol (HFIP) groups, HCSFA2, was employed. HCSFA2 exhibits a high but reversible affinity for hazardous vapors with HB basic properties such as the phosphonate ester G-nerve agents. Using conventional benchtop ATR-FTIR spectroscopy the HFIP hydroxyl stretch for HCSFA2 has been observed in this work to shift by up to 800 wavenumbers when exposed to a strong HB base. The amount of shift is directly related to the HB basicity of the vapor. To take advantage of this and related spectral changes we have developed different types of microfabricated transducer structures suitable for sorbent coating and interrogation with a tunable IR light source to observe these molecular interactions. In one device we use a sorbent coated microbridge structure and micromechanical photothermal spectroscopy to monitor spectral changes when a vapor docks with HCSFA2. In a second device approach we utilize evanescent-field absorption spectroscopy in a silicon nitride (SiN) microring resonator, coated with the HCSFA2 sorbent, to monitor vapor interactions. Example ATR-FTIR and microfabricated transducer spectra with exposures to dimethylmethylphosphonate (DMMP, G-nerve simulant and precursor) will be shown to illustrate the potential of these technologies.

9101-7, Session 2

Recent developments towards MEMS based spectrometers *(Invited Paper)*

Dilusha K. K. M. B. Silva, John M. Dell, Lorenzo Faraone, The Univ. of Western Australia (Australia)

Infrared (IR) spectroscopy is finding increasing application in numerous industries including, pharmaceuticals, agriculture, viticulture, remote sensing, and defense. Examples of the measurable quantities include, levels of protein, starch, oil and moisture content of grains, and total carbon and mineralisable nitrogen in soils. The main limiting factors to widespread deployment of this technology are presently, the capital and maintenance costs of the spectroscopy equipment; sensitivity to vibration and shocks; and calibration maintenance. Particularly for application in Agriculture and the minerals industry, the need for low cost, small and rugged spectroscopy instruments is immense.

Microelectromechanical systems (MEMS) based microspectrometers have the potential to address all of these issues. They can be low cost, are intrinsically mechanically rugged, and are potentially self-calibrating. The MEMS microspectrometer, developed at UWA is based on a MEMS micromachined Fabry-Perot optical filter, integrated with a photodetector. The optical filter consists of two mirrors separated by an air-gap, and an actuation mechanism to vary the size of the air-gap. This filter allows only a narrow band of optical wavelengths to pass through onto the photodetector. The photodetector is located directly below the bottom mirror of the filter. A typical microspectrometer shows a wavelength-tuning range of roughly 900 nm, corresponding to 50% of the un-deflected mirror separation, and a spectral resolution in the order of 40 nm.

In this talk, some of our latest work on the microspectrometer will be presented, including the results of new mirror designs aimed at significantly improving spectral resolution and wavelength tuning range.

9101-8, Session 2

Optical design of MOEMS-based micromechatronic modules for applications in spectroscopy

Andreas Tortschanoff, Matthias Kremer, Carinthian Tech Research AG (Austria); Thilo Sandner, Fraunhofer-Institut für Photonische Mikrosysteme (Germany); Andreas Kenda, Carinthian Tech Research AG (Austria)

Electrostatically driven MOEMS (micro-opto-elctro-mechanical systems) scanner devices have many applications in the fields of optics, telecommunications and spectroscopy. Besides flat scanner mirrors, also more sophisticated MOEMS based optical elements (e.g. translational devices or scanning gratings) have been realised, which enable compact, fast and cost-effective spectroscopic devices.

One of the important challenges for widespread application of MOEMS devices is to provide a modular interface, for easy handling and accurate driving of the MOEMS elements, in order to enable seamless integration in larger spectroscopic system solutions. In particular position feedback has to be provided in order to assure stable, accurate, and fast scanner operation with well controlled amplitude under varying environmental conditions. Recently, we have developed compact modules comprising optical position sensing, and driver electronics, with closed loop control, which can actively control electrostatically driven 2D-micro-scanners.

In this contribution we present in much detail the optical design of the MOEMS driver modules, which has to provide the optimal compromise between the requirements for small size and simplicity on the one hand and optical accuracy on the other. Furthermore we will present concepts for compact spectroscopic devices, based on different MOEMS scanner modules with 1D and 2D optical elements. This includes MOEMS-based monochromator-designs as well as variable focus scanner devices, which we have realized recently.

9101-9, Session 2

Compact multispectral photodiode arrays using micropatterned dichroic filters

Dave Fish, Randel Mercer, Pixelteq, Inc. (United States)

The next generation of multispectral instruments needs to deliver significant improvements in both spectral band customization and portability to support the widespread deployment of application-specific optical sensors. The benefits of spectroscopy are well established for numerous applications including biomedical instrumentation, industrial sorting & sensing, chemical detection, and environmental monitoring. Spectroscopy, hyperspectral, and multispectral measurements are considered – evaluating the technology, tradeoffs and application fit of each. In the vast majority of applications, monitoring 4-8 targeted spectral bands of optimized wavelength and bandwidth provides the spectral contrast and correlation required. An innovative approach integrates precision spectral filters at the photodetector level to enable smaller sensors, simplify optical designs, and reduce device integration costs. This method supports user-defined spectral bands to create application-specific sensors in a small footprint with scalable cost efficiencies.

A range of design configurations, filter options and combinations are presented together with typical applications – from basic multi-band detection to stringent multi-channel fluorescence measurement. One example implementation packages 8 narrowband photodiodes (VIS, NIR) into a 9x9mm LCC footprint for multispectral applications from portable color monitors to purpose-built OEM industrial and scientific instruments. Use of a multispectral photodiode array typically eliminates 10-20 components from the device BOM, streamlining the optical path and shrinking the footprint 50% or more. A stepwise design approach for multispectral sensors is discussed - including spectral band definition, optical design tradeoffs and constraints, and device integration from prototype through scalable volume production. Additional customization options are explored for application-specific OEM sensors using multispectral photodiode arrays for portable devices.

9101-24, Session 2

Pure rotational spectrometers for trace-level VOC detection and chemical analysis

Justin L. Neill, Brent J. Harris, Robin L. Pulliam, Matt T. Muckle, Roger Reynolds, David McDaniel, BrightSpec (United States); Brooks H. Pate, BrightSpec (United States) and Univ. of Virginia (United States)

Pure rotational spectroscopy in the centimeter, millimeter, and THz regions of the electromagnetic spectrum is a powerful technique for the characterization of polar molecules in the gas phase. Although this technology has a long history in the research sector for structural characterization, recent advances in digital electronics have only recently made commercial instruments competitive with established chemical analysis techniques. BrightSpec is introducing a platform of pure rotational spectrometers in response to critical unmet needs in chemical analysis. These instruments aim to deliver the operational simplicity of Fourier Transform infrared spectrometers in conjunction with the chemical analysis capabilities of mass spectrometers. In particular, the BrightSpec ONE instrument is a broadband gas mixture analyzer with full capabilities for chemical analysis. This instrument implements Fourier transform millimeter-wave emission spectroscopy, wherein a brief excitation pulse is applied to the sample, followed by the measurement of the coherent free induction decay (FID) responses of all molecular transitions within the excitation bandwidth. After sample injection and characterization, the spectrometer returns a list of all known species detected in the sample, along with their concentrations in the mixture. No prior knowledge about the sample composition is required. The instrument can then perform double-resonance measurements (analogous to 2-D COSY NMR), direct mass determination through the time profile of the molecular FID, and automated isotopic identification as part of a suite of tools that can return the structural identity of the unknowns in the sample.

9101-10, Session 3

Advances in miniature spectrometer and sensor development *(Invited Paper)*

Jouko O. Malinen, Anna Rissanen, Heikki K. Saari, Pentti Karioja, VTT Technical Research Ctr. of Finland (Finland)

Miniaturization and cost reduction of spectrometer technologies has great potential to open up new applications areas and business opportunities for analytical technology in hand held, mobile and on-line applications. There is a significant ongoing change in spectrometer technology, powered partly by the business needs and partly by maturing of the enabling technologies. Advances in microfabrication have resulted in high-performance MEMS and MOEMS devices for spectrometer applications. Many other enabling technologies are useful for miniature analytical solutions, such as microphotonics production, techniques for electronics and sensor integration, 3D printing, powerful embedded computing platforms, networked solutions as well as advances in chemometrics modeling.

This paper will summarize recent work on spectrometer miniaturization at VTT Technical Research Centre of Finland. Fabry-Perot interferometer (FPI) tunable filter technology has been developed in two technical versions: Piezo-actuated FPIs have been applied in miniature hyperspectral imaging needs in light weight UAV and nanosatellite applications, chemical imaging as well as medical applications. Microfabricated MOEMS FPIs have been developed as cost-effective sensor platforms for visible, NIR and IR applications. Further examples of sensor miniaturization will be discussed, including a MEMS-based photoacoustic gas sensor as well as roll-to-roll printed Surface Enhanced Raman Scattering (SERS) sensor technology for pharmaceutical and environmental applications. Practical examples of sensor integration will be discussed, supplemented by first results from recent application studies.

9101-11, Session 3

High-pressure mass spectrometry

Christopher D. Brown, 908 Devices Inc. (United States)

The last decade has witnessed a remarkable reduction in the size of some high performance analytical instruments. High resolution Raman and FTIR systems are now available in 2-3 pound handhelds, completely automated and purpose-built for applications such as unknown material identification, pharmaceutical raw-material release, counterfeit drug detection, and street testing for drug substances. Similar miniaturization of mass spectrometers has long been discussed as imminent, and certainly progress has been made to luggable form factors for safety and security applications, but truly handheld form factors have thus far proven elusive. Novel micro-scale ion-trap geometries have very recently been demonstrated operating at pressures 3-4 orders of magnitude higher than conventional ion trap mass spectrometers. These pressure regimes fundamentally alter the required volume of the ion traps, instrument vacuum pumping burden, and drive electronics resulting in self-contained MS systems weighing 3-4 pounds with continuous flow rates of >3 sccm. The theory and history of these micro-scale trap advances will be reviewed, along with recent engineering and performance achievements leading to complete MS systems in the 3-4 lb range. Tradeoffs in performance, size and automation will also be reviewed in the context of results and examples from prominent multimode safety and security detection applications.

9101-12, Session 3

Multivariate optical element platform for compressed detection of fluorescence markers

Ryan J. Priore, CIRTEMO (United States)

The success of a commercial fluorescent diagnostic assay is dependent on the selection of a fluorescent biomarker; due to the broad nature of fluorescence biomarker emission profiles, only a small number of fluorescence biomarkers may be discriminated from each other as a function of excitation source. Multivariate Optical Elements (MOEs) are thin-film devices that encode a broad band, spectroscopic pattern allowing a simple broadband detector to generate a highly sensitive and specific detection for a target analyte. MOEs have historically been matched 1:1 to a discrete analyte or class prediction; however, MOE filter sets are capable of sensing projections of the original sparse spectroscopic space enabling a small set of MOEs to discriminate a multitude of target analytes. This optical regression can offer real-time measurements with relatively high signal-to-noise ratio that realize the advantages of multiplexed detection and pattern recognition in a simple optical instrument. The specificity advantage of MOE-based sensors allows fluorescent biomarkers that were once incapable of discrimination from one another via optical bandpass filters to be employed in a common assay panel. A simplified MOE-based sensor may ultimately reduce the requirement for highly trained operators as well as move certain life science applications like disease prognostication from the laboratory to the point of care. This presentation will summarize the design and fabrication of compressed detection MOE filter sets for detecting multiple fluorescent biomarkers simultaneously with strong spectroscopic interference as well as comparing the detection performance of the MOE sensor with traditional optical bandpass filter methodologies.

9101-13, Session 3

Low-cost photonic crystal spectral sensors made by projection lithography

Tanya C. Garza, James I. Scholtz, Michael J. Gazes, Chromation (United States); Ioannis Kymissis, Chromation (United States) and Columbia Univ. (United States); Nadia K. Pervez, Chromation (United States)

Nanophotonic structures developed for spectral sensing include photonic crystals, plasmonics, and other subwavelength structures. High-throughput scalable fabrication techniques are critical for fabrication of low-cost components. Fabrication of these structures typically requires expensive and slow processes which produce high quality structures such as electron beam lithography. Alternatively, projection lithography is a fast, inexpensive, fabrication process which is standard in the fabrication industry for batch fabricating features reproducibly. We have successfully pushed the limits of projection lithography produce a low-cost, high-throughput alternative to electron beam lithography for our nanoscale, visible-wavelength photonic crystal spectral sensors. This nanofabrication process allows for the production of spectral sensors for an order of magnitude less cost and time.

9101-14, Session 4

Mid-infrared distributed feedback interband cascade lasers for spectroscopic applications

Lars Naehle, nanoplus GmbH (Germany)

In recent years the importance of lasers in optical gas sensing has been continuously increasing. Tunable Laser Absorption Spectroscopy (TLAS) has proven to be a versatile tool in modern environmental analysis. In the mid-infrared wavelength region between 3 and 6 μm, which is of high interest for sensing applications, Interband Cascade Lasers (ICL) can provide monomode continuous wave (CW) emission at room temperature. We present the simulation, design and manufacturing of distributed feedback (DFB) laser devices based on this concept, with focus on devices that target specific, technologically and industrially relevant, wavelengths with low energy consumption. Finally application-grade devices from 3 to 6 μm are presented. CW operation above room temperature and tuning ranges of 11 nm with Side Mode Suppression Ratios (SMSR) greater 30 dB were achieved.

9101-15, Session 4

Current and emerging laser sensors for greenhouse gas sensing and leak detection

Michael B. Frish, Physical Sciences Inc. (United States)

To reduce atmospheric accumulation of the greenhouse gases methane and carbon dioxide, emissions from natural gas extraction, transmission, distribution, and combustion processes should be controlled and minimized. Currently, handheld and airborne laser sensors are accepted industry tools for periodic surveys to detect leaks from the gas pipeline infrastructure. However, to identify intermittent leak sources and better quantify emissions, networks of permanent widely-deployed sensors are desirable to continuously monitor and map, spatially and temporally, sources of escaping methane and carbon dioxide. Sensors for these networks must provide sufficient sensitivity and resolution to distinguish local sources from ambient background, and provide fast health and safety danger alerts. They must be suitable for widespread cost-effective deployment, autonomous, accurate, and reliable in compact packages.

This paper describes recent advances in laser-based leak detectors, focusing on permanently-installed, wireless, solar-powered open-path sensors that overcome previous installation and maintenance difficulties while providing autonomous real-time leak reporting without false alarms. During more than six-months of field testing, aiming of the laser from a methane sensor's transceiver to passive targets up to 600 ft distant was stable and required no maintenance. Leak challenges originating up to 70 ft upwind of the laser path demonstrated detection of methane emission rates as small as 0.5 scfh.

The paper concludes with some of the technical and economic challenges that must be addressed to realize widespread sensor deployment for "ubiquitous monitoring", including the emerging need for laser sources designed with power and cost attributes specifically intended to fulfill these sensor requirements.

9101-16, Session 4

The design and performance characterization of a tunable external cavity quantum cascade laser utilizing thermo-optically tuned thin film filters

Don Kuehl, Eugene Y. Ma, Chip Marshall, Jinhong Kim, Richard Sharp, RedShift Systems Corp. (United States)

Quantum Cascade Lasers (QCLs) and Interband Cascade Lasers (ICLs) are promising new mid-IR sources for spectroscopic applications. Desirable characteristics include extremely high brightness, broad range emission, very high resolution, compact size, and modest power consumption. For most spectroscopic applications, it is necessary to tune QCLs over a broad emission wavelength range. The conventional approach for broad range tuning is to use an external cavity (EC) which incorporates a mechanically tuned diffraction grating within the laser cavity.

In this paper we will describe an alternative approach to EC-QCL tuning which utilizes a pair of miniature, thermally tuned, MEMS fabricated etalon filters. These filters are inserted in the laser cavity between a single lens and an output coupling mirror allowing for a very compact, simple, mechanically stable package with no moving parts. The thermal mass of the transmission filters is very small which allows for rapid tuning of the laser across the QCL emission range. The optical properties of the paired filters allow for efficient data collection across separated regions of continuous tuning, as well as the ability to rapidly "hop" to arbitrary wavelengths and make discrete single point measurements. If a short scan piezo actuator is used in the external cavity, high resolution mode-hop-free continuous wave scanning suitable for multi-line quantitative gas measurements can also be performed.

9101-17, Session 4

A spectroscopic tool for identifying fragments and sources of origin for materials of military interest

Andrzej W. Miziolek, Frank C. De Lucia Jr., U.S. Army Research Lab. (United States)

There is a need to identify fragments of munitions that are associated with casualties as well as the source of origin for various materials used in areas of conflict including explosives, their ingredients, and ammunition. Both fieldable systems (man-portable or handheld) as well as benchtop systems in field laboratories are desired for screening and attribution purposes. Laser Induced Breakdown Spectroscopy (LIBS) has been demonstrated in recent years as a promising new tool for materials identification, matching, and provenance. With the use of the broadband, high resolution spectrometer systems, the LIBS devices not only track the elemental inventory of the sample, but also are capable of elemental fingerprinting to signify sources of origin of various materials. This talk will present the results of recent studies and will discuss the progress and practicality of the LIBS technology for field use.

9101-18, Session 4

Portable, real-time alloy identification of metallic wear debris from machinery lubrication systems: laser-induced breakdown spectroscopy versus x-ray fluorescence

Pooja Suresh, GasTOPS Ltd. (Canada)

Alloy identification of oil-borne wear debris captured on chip detectors, filters and magnetic plugs allows the machinery maintainer to assess the health of the engine or gearbox and identify specific component damage. Today, such identification can be achieved in real time using portable / at-line laser-induced breakdown spectroscopy (LIBS) and X-ray fluorescence (XRF) instruments. Both techniques can be utilized in various industries including aviation, marine, railways, heavy diesel and other industrial machinery with, however, some substantial differences in application and instrument performance. In this work, the performances of a LIBS and an XRF instrument (developed with author's contribution) are compared based on measurements of a wide range of typical aerospace alloys including steels, titanium, aluminum and nickel alloys. Measurement results were analyzed with a staged parametric correlation technique specifically developed for the purposes of this study - identifying the particle alloy composition using a pre-recorded library of spectral signatures. The analysis is performed in two stages: first, the base element of the alloy is determined by correlation with the stored elemental spectra and then, the alloy is identified by matching the particle's spectral signature using parametric correlations against the stored spectra of all alloys that have the same base element. The correlation analysis has achieved excellent discrimination between alloys with very similar composition. Portable LIBS demonstrates higher detection accuracy and better quantitative identification of alloys comprising lighter elements as compared to a portable XRF system, and reveals a significant reduction in the analysis time over XRF.

9101-19, Session 4

Approaching the PPB detection limits for copper in water using laser induced breakdown spectroscopy

Walid T. Mohamed, King Saud Univ. (Saudi Arabia) and Cairo Univ. (Egypt); Sausan Sawaf, King Saud Univ. (Saudi Arabia)

Copper concentrations in drinking-water is very important to be monitored which can cause cancer if it exceed about 10 mg/liter. In the present work, we have developed a simple, low laser power method to improve the detection limits of laser induced plasma spectroscopy LIBS for copper in aqueous solutions with different concentrations. In this method a medium-density fiberboard (MDF) wood have been used as a substrate that absorbs the liquid sample to transform laser liquid interaction to laser solid interaction. Using the fundamental wavelength of Nd:YAG laser, the constructed plasma emissions were monitored for elemental analysis. The signal-to-noise ratio SNR was optimized using low laser fluence of 32 J cm-2, and detector (CDD camera) gate delay of 0.5 ?s. Both the electron temperature and density of the induced plasma were determined using Boltzmann plot and the FWHM of the Cu at 324.7 nm, respectively. The plasma temperature was found to be 1.197 eV, while the plasma density was about 3 ? 10^16 cm^-3. The detection limits for Cu at 324.7 nm is found to be 131 ppb comparable to the results by others using complicated system.

9101-20, Session 4

Laser-induced breakdown spectroscopy and spectral analysis of improvised explosive materials

Amy J. R. Bauer, Applied Research Associates, Inc. (United States); Andrzej W. Miziolek, U.S. Army Research Lab. (United States)

There exists an unmet need in the discovery and identification of certain improvised explosive (IE) materials. IE contain a wide range of materials, many of which are not well classified by available hand-held tools, especially metal powders and food products. Available measurement approaches are based in the identification of specific sub-groups such as nitro/nitrate and chlorate/perchlorate, normally with Raman spectroscopy. The presence of metal powders is not detected by these approaches, and further the powders themselves scatter the laser radiation used in the excitation of the spectra, making other components more difficult to discern.

Preliminary work with laser-induced breakdown spectroscopy (LIBS) shows that metal powders are easily detected and differentiated. This early work also suggests that chlorine in different anions can be distinguished. The work presented in this talk will build on that previous work, expanded to new compounds, and subjected to more rigorous analytical tools, including principal components analysis.

9101-22, Session 5

Continuously sample, trap, and measure Raman spectra of individual single airborne particles

Yongle Pan, U.S. Army Research Lab. (United States); Chuji Wang, Mississippi State Univ. (United States); Mark Coleman, U.S. Army Research Lab. (United States); Joshua L. Santarpia, Sandia National Labs. (United States)

To measure Raman spectra and observe other dynamic characteristics of single particles trapped in air will be a powerful analytical method. The capability of trapping absorbing particles using photophoretic force has been successfully demonstrated recently [1]. The key problem for developing this trapping technique into an on-line analytical tool that can continuously sample, trap, measure, and release the particle is the difficulty

in drawing particles into the trap at a sufficient rate, while slowing enough the particles in the trapping volume so that they can be captured and trapped. Here we present an innovative experimental setup to overcome this problem. A special aerodynamic co-axis double nozzle design is used for controlling the aerosol particles by adapting the virtual impaction principle to reduce the particle speed to make trapping easier while maintaining sufficient sampling rate. Aerosol is sampled at 0.5 L/min and passes through a 0.8 mm diameter interior nozzle, which focuses the aerosol into a <300 μm diameter stream moving around 10 m/sec. A second 1.2 mm diameter exterior nozzle is employed to draw air backwards reversed from the usual sheath nozzle approach. This carries away most of the airflow in a direction opposite to the aerosol stream and greatly reduces the particle speed to 0.2 m/sec or less. Therefore, photophoretic forces are sufficient enough to stop and trap the particles in significantly reduced momentum. We have successfully captured and trapped moving absorbing particles as long as we required for long-time measurement and observation using our special trap formed by a low-light-intensity biconical light region. Various Raman spectra from single trapped microsized particle have been obtained and analyzed.

1. Y. L. Pan et al, "Photophoretic trapping of absorbing particles in air and measurement of their single-particle Raman spectra," Optics Express, 20 (5), 5325 (2012)

9101-23, Session 5

Pocket-size near-infrared spectrometer for narcotic materials identification

Nada A. O'Brien, Christopher G. Pederson, Donald M. Friedrich, Chang Hsiung, Marc von Gunten, JDSU (United States)

While significant progress has been made towards the miniaturization of Raman, mid-infrared (IR), and near-infrared (NIR) spectrometers for homeland security and law enforcement applications, there remains continued interest in pushing the technology envelope for smaller, lower cost, and easier to use analyzers. In this paper, we report on the use of an ultra-compact, handheld near infrared (NIR) spectrometer, the MicroNIR Spectrometer, that weighs less than 60 grams and measures<50mm in diameter for the classification of 138 different substances most of which are controlled substances (such as cocaine, heroin, oxycodone, diazepam), as well as synthetic cathinones (also known as bath salts), and synthetic cannabinoids. A library of the materials was created from a master MicroNIR spectrometer, then a set of 25 unknown samples were identified with three other MicroNIRs showing, 1) the ability to correctly identify the unknown with a very low rate of misidentification, and 2) the ability to use the same library with multiple instruments. In addition, we will show that through the use of innovative chemometric algorithms, we are able to identify the individual compounds that make up an unknown mixture based on the spectral library of the individual compounds only. The small size of the spectrometer is enabled through the use of high-performance linear variable filter (LVF) technology [1]. The spectrometer is powered with a smart mobile device leveraging 'cloud' computing.

1. N. O'Brien, et al, "Miniature Near-Infrared Spectrometer Engine For Handheld Applications" Proc. SPIE, Ed. M. Druy, and R. Crocombe, 8374, p 837404-1-8 (2012).

9101-25, Session 5

A novel Raman microspectrometer architecture for single bacteria identification

Samy Andrea Strola, Emmanuelle Schultz, Cédric P. Allier, CEA-LETI-Minatec (France); Anne-Catherine Simon, Isabelle Espagnon, CEA LIST (France); Patricia Claustre, Dorothée Jary, Jean-Marc Dinten, CEA-LETI-Minatec (France)

The paper presents a novel compact Raman microspectrometer architecture aimed at analyzing single bacteria. In this setup, the bulky microscope, commonly used in microspectrometers to detect and target single bacteria, is replaced with a 24mm2 lensfree imaging device. An x100 objective remains to focalize laser light onto single bacteria by means of XYZ stages, and to collect back-scattered Raman signal. At first a 5 μl droplet of controlled optical density bacteria dispersed in water matrix, is deposited on a quartz substrate placed on top of the lensfree imaging device. The operator detects single bacteria over a large field of view 24mm2. He further targets the laser onto the single bacteria of choice by monitoring the elastic diffusion pattern resulting from the interaction of the laser probe (30mW at 532nm) with the single bacterium. Once the alignment over the single bacterium is optimized, we collect its comprehensive Raman spectrum. This targeting method is fast (60 spectra per hour in manual operation), and accurate enough to provide a precise Raman chemical fingerprint analysis of single bacteria in the range of 600-3300 cm-1. By combining the morphological signature obtained from lensfree images, and the fine biochemical fingerprint yielded by the Raman spectra, we show that promising differentiation scores (>82%) are obtained for a particular strain of Bacillus among an initial bacteria database. This case study paves the way to a new generation of portable spectrometers for rapid and marker-free identification of bacterial pathogens in real samples.

9101-26, Session 5

Sensitive algorithm for multiple-excitation-wavelength resonance Raman spectroscopy

Balakishore Yellampalle, Hai-Shan Wu, William B. McCormick, Mikhail Sluch, Robert B. Martin, Robert V. Ice, Brian E. Lemoff, West Virginia High Technology Consortium Foundation (United States)

Raman spectroscopy is a widely used spectroscopic technique with a number of applications. During the past few years, we explored the use of simultaneous multiple-excitation-wavelengths (MEW) in resonance Raman spectroscopy. This approach takes advantage of Raman band intensity variations across the Resonance Raman spectra obtained from two or more excitation wavelengths. Amplitude variations occur between corresponding Raman bands in Resonance Raman spectra due to complex interplay of resonant enhancement, self-absorption and laser penetration depth. We have developed a very sensitive algorithm to estimate concentration of an analyte from spectra obtained using the MEW technique. The algorithm uses correlations and least-square minimization approach to calculate an estimate for the concentration. For two or more excitation wavelengths, measured spectra were stacked in a two dimensional matrix. In a simple realization of the algorithm, we approximated peaks in the ideal library spectra as triangles. In this work, we present the performance of the algorithm with measurements obtained from a dual-excitation-wavelength Resonance Raman sensor. The novel sensor, developed at WVHTC, detects explosives from a standoff distance. The algorithm was able to detect explosives with very high sensitivity even at signal-to-noise ratios as low as ~1.6. Receiver operating characteristics calculated using the algorithm showed a clear benefit in using the dual-excitation-wavelength technique over single-excitation-wavelength techniques. Variants of the algorithm that add more weight to amplitude variation information showed improved specificity to closely resembling spectra. We also compare the performance with results obtained from algorithms traditionally used in Raman spectroscopy.

9101-27, Session 5

Advancements in the detection of explosives using a Raman handheld instrument (ACE ID)

Josep Arnó, Michael Frunzi, Brian Sparano, Paul Hetherington, David Valovich, David St. Pierre, Smiths Detection (United States)

Raman spectroscopy is the technology of choice to identify bulk solid and liquid phase unknown samples without the need to contact the substance. Materials can be identified through translucent and semi-translucent containers such as plastic and glass. ConOps in emergency response and military field applications require the redesign of conventional desktop

units for: field portability; shock, thermal, and chemical attack resistance; easy and intuitive use in restrictive gear; reduced size, weight, and power. This article introduces a new handheld instrument (ACE-ID) designed to take Raman technology to the next level in terms of size, safety, speed, and analytical performance. ACE-ID is ruggedized for use in severe climates and terrains. It is lightweight and can be operated with just one hand. An intuitive software interface guides users through the entire identification process, making it easy-to-use by personnel of different skill levels including military explosive ordinance disposal technicians, civilian bomb squads and hazmat teams. Through the use of embedded advanced algorithms, the instrument is capable of provide fluorescence correction and analysis of binary mixtures. Instrument calibration is performed automatically on startup without requiring user intervention. ACE ID incorporates an optical rastering system that spreads out the laser energy over the sample. This important innovation significantly reduces the heat induced in dark samples and the probability of ignition of susceptible explosive materials. In this article, the performance of the instrument for the identification of explosives will be provided in addition to a quantitative evaluation of the safety improvements derived from the reduced ignition probabilities of representative explosives.

9101-29, Session 6

An FT-IR performance simulator to guide design decisions for miniature FT-IR spectrometers

David W. Schiering, John T. Stein, Michael Frunzi, Peng Zou, Smiths Detection (United States)

In the last decade, portable and hand-held Fourier Transform infrared (FT-IR) spectrometers have become important tools for materials characterization and identification outside of the laboratory, in hostile environments, while being used by persons without scientific training. The performance, physical, and ergonomic demands placed on design have created a need for automated FT-IR spectroscopic performance simulation to predict performance while pushing the boundaries of miniaturization, rationalize error budgeting, and analyze system or component anomalies. The present work relates to an automated simulator that allows the designer to alter various input parameters including geometric optics, source brightness, optical materials and coatings efficiencies, detector characteristics, noise sources, numerical processing, and to output calculated interferograms and spectra. The performance of the simulator will be evaluated for a few representative case studies – the optical design footprint of a miniature FT-IR spectrometer, designing the frequency response of the signal channel, and analog-to-digital converter quantization sizing.

9101-30, Session 6

A military grade field usable Raman analyzer: measurement of captured fuels

Stuart R. Farquharson, Wayne W. Smith, Carl R. Brouillette, Real-Time Analyzers, Inc. (United States)

Portable Raman analyzers have emerged during the first part of this century as an important field tool for crime scene and forensic analysis, primarily for their ability to identify unknown substances. This ability is also important to the US military, which has been investigating such analyzers for identification of explosive materials that may be used to produce improvised explosive devices, chemicals that may be used to produce chemical warfare agents, and fuels in storage tanks that may be used to power US military vehicles. However, the use of such portable analyzers requires that they meet stringent military standards (specifically MIL-STD 810G). These requirements include among others: 1) light weight and small size (< 35 pounds, < 3 cu. ft.), 2) vibration and shock resistant (26 four foot drops), 3) operation from -4 to 110 oF, 4) operation in blowing dust, sand and rain, 5) battery operation, and of course 6) safe operation (no laser or shock hazards). This presentation will describe a portable Raman analyzer that meets all of these requirements, and measurements of fuels.

9101-31, Session 6

Detection of chemical warfare simulants using Raman excitation at 1064 nm

Mark Mabry, Claire Dentinger, Claude Robotham, Rigaku Raman Technologies (United States)

Raman spectroscopy is a powerful technique for material identification. The technique is sensitive to primary and higher ordered molecular structure and can be used to identify unknown materials by comparison with spectral reference libraries. Additionally, miniaturization of opto-electronic components has permitted development of portable Raman analyzers that can be field deployed. Raman scattering is a relatively weak effect compared to a competing phenomenon, fluorescence. Even a moderate amount of fluorescence background interference can easily prevent identification of unknown materials. A long wavelength Raman system is less likely to induce fluorescence from a wider variety of materials than a higher energy visible laser system.

Compounds such as methyl salicylate, diethyl malonate, and bis-(2-ethylhexyl) phosphite are used as physical chemical warfare agent (CWA) simulants for development of analytical detection strategies. Field detection of these physical simulants however poses unique challenges because threat identification must be made quickly without the turnaround time usually required for a laboratory based analysis. Fortunately, these CWA simulants are good Raman scatterers and field based detection using portable Raman instruments is promising. Measurements of the CWA simulants were done using a 1064 nm based portable Raman spectrometer. The longer wavelength excitation laser was chosen relative to a visible based laser systems because the 1064 nm based spectrometer is less likely to induce fluorescence and more suitable to a wider range of materials. Since these materials are physical simulants different sample presentations were also investigated.

9101-48, Session 6

Combination of a spectrometer-on-chip and an array of Young's interferometers for laser spectrum monitoring

A. Koshelev, Nano-Optic Devices (United States); G. Calafiore, C. Peroz, abeam Technologies, Inc. (United States); S. Dhuey, S. Cabrini, Lawrence Berkeley National Lab. (United States); P. Sasorov, A. Goltsov, Nano-Optic Devices (United States)

Integrated optics allows for the development of a compact, robust and suitable for mass production on-chip spectrometers. One of the main applications of the spectrometer-on-chip is a monitoring of laser spectrum since single mode devices benefit from the high brightness of the source. By combining spectrometer-on-chip based on digital planar holopraphy (DPH) with an array of Young's interferometers we are able to overcome a usual tradeoff between spectral range and resolution for this specific application. DPH measures a spectrum in a broad spectral range of ~100 nm with a resolution of ~0.15 nm while Young's interferometers provide spectral width and wavelength measurement with an accuracy of several pm.

9101-32, Session 7

Remote gas sensing and imaging with NASA's hyperspectral thermal emission spectrometer (HYTES)

William R. Johnson, Glynn Hulley, Simon J. Hook, Jet Propulsion Lab. (United States)

The hyperspectral thermal emission spectrometer was developed under the instrument incubator program and has now completed three deployments.

The scan head uses a state-of-the-art Dyson spectrometer cooled to 100K coupled to a quantum well infrared photodetector array held at 40K. The combination allows for 256 spectral channels between 7.5µm and 12µm with 512 cross track spatial pixels. Spectral features for many interesting gases fall within the instrument passband.

We show positive gas plume detection at ranges >1000m for various cases: Ammonia gas detection from Salton Sea fumaroles, Methane detection from staged releases points in Wyoming and off the coast of Santa Barbara.

9101-33, Session 7

Miniaturized handheld hyperspectral imager

Huawen O. Wu, Eric A. Bergles, William Yang, Charlie Zhang, BaySpec Inc. (United States)

High-end spectral imagers used in satellite, airborne or stand-off reconnaissance and surveillance systems, although revolutionary, are still expensive, bulky and complex to use. Bulky glass lenses and the mechanical movements to achieve focus and zoom are hampering the development of truly compact high-quality spectral imagers. A miniaturized spectral imager is shown with the image sensor integrated at the level of the chip itself, removing the need for expensive, bulky and complex optics that are used as scientific instruments today. The result is a handheld spectral imager weighing less than 0.5 lbs. (227 mg) including on-board computing, display and battery. Available with wide range of objective lenses for wide angle to close-up views enabling real-time Hyperspectral imaging at video rates. Suitable for installation on miniature UAV drones or conveyor belts on production lines. Eventually, small handhelds could be adapted for use in outpatient medical clinics for point of care diagnostics and other in-field applications. The design of the hyperspectral imager, characterization results and sample measurement results are presented.

9101-34, Session 7

Spectral imaging and standoff sensing with HTVS technology

Bradford B. Behr, Tornado Spectral Systems (United States); Yusuf Bismilla, Andrew T. Cenko, Brandon DesRoches, Jeffrey T. Meade, Elizabeth A. Munro, Jared Slaa, Arsen R. Hajian, Tornado Spectral Systems (Canada)

Tornado Spectral Systems (TSS) has developed High Throughput Virtual Slit (HTVS) technology that improves the performance of spectrometers by factors of several while maintaining system size. In the simplest configuration, the HTVS allows optical designers to remove the lossy slit from a spectrometer, greatly increasing throughput without a loss of resolution. This is especially useful in many standoff applications, where every photon matters.

TSS has tested multiple configurations of HTVS spectral sensing and spectral imaging technology, including standoff sensing, point scan imaging, long-slit pushbroom imaging and similar configurations. The HTVS throughput-resolution advantage allows us to increase scanning speed, decrease system size, decrease aperture, decrease source intensity requirements or some combination of all four. HTVS technology expands the realm of viable spectral imaging applications.

We discuss the applicability of this technology to spectral imaging and standoff sensing and present experimental results from several of prototype and production spectrometers.

9101-35, Session 7

Dynamic 3D chemical agent cloud mapping using a sensor constellation deployed on mobile platforms

Bogdan R. Cosofret, Daisei Konno, David C. Rossi, William J. Marinelli, Physical Sciences Inc. (United States); Peter R. Seem, Physical Sciences Inc (United States)

The need for standoff detection technology to provide early CB threat warning is well documented. Much of the information obtained by a single passive sensor is limited to bearing and angular extent of the threat cloud. In order to obtain absolute geo-location, 3-D extent and detailed composition of the chemical threat, fusion of information from multiple passive sensors is needed. A capability that provides on-the-move and comprehensive chemical cloud characterization is key to the development of real-time Battlespace Awareness. We have developed, implemented and tested algorithms and hardware to perform the fusion of information obtained from two mobile LWIR passive hyperspectral sensors. The implementation of the capability is driven by current Nuclear, Biological and Chemical Reconnaissance Vehicle operational tactics and represents a mission focused alternative of the already demonstrated 5-sensor static Range Test Validation System. The new capability consists of hardware for sensor pointing and attitude information which is made available for streaming and aggregation as part of the data fusion process for threat characterization. Cloud information is generated using 2-sensor data ingested into a suite of triangulation and tomographic reconstruction algorithms that are amenable to using a limited number of projections and unfavorable geometries resulting from on-the-move operation. In this paper we describe the system architecture and present an analysis of results and lessons learned during testing of the system at Dugway Proving Ground, BioWeek 2013.

9101-36, Session 7

LWIR hyperspectral micro-imager for detection of trace explosive particles

Adam L. Bingham, Spectrum Photonics, Inc. (United States); Paul G. Lucey, Univ. of Hawai'i (United States); Jason T. Akagi, John L. Hinrichs, Edward T. Knobbe, Spectrum Photonics, Inc. (United States)

Chemical micro-imaging is a powerful tool for the detection and identification of analytes of interest against a cluttered background (i.e. trace explosive particles left behind in a fingerprint). While a variety of groups have demonstrated the efficacy of Raman instruments for these applications, Spectrum Photonics has developed and demonstrated a prototype system utilizing long wave infrared hyperspectral microscopy (LWIR HSM), which enables the simultaneous collection of LWIR reflectance spectra from 8-14 µm for the entire field of view. Results showcasing the detection of trace explosive particulates will be presented.

9101-37, Session 7

A compact Fourier transform imaging spectrometer employing a variable gap Fabry-Perot interferometer

Paul G. Lucey, Univ. of Hawai'i (United States); Adam L. Bingham, John L. Hinrichs, Jason T. Akagi, Edward T. Knobbe, Spectrum Photonics, Inc. (United States)

Fourier transform spectroscopy is a widely employed method for obtaining visible and infrared spectral imagery, with applications ranging from the desktop to remote sensing. Most fielded Fourier transform spectrometers (FTS) employ the Michelson interferometer and measure the spectrum

encoded in a time-varying signal imposed by the source spectrum interaction with the interferometer. A second, less widely used form of FTS is the spatial FTS, where the spectrum is encoded in a pattern sampled by a detector array.

Recently we described using a Fabry-Perot interferometer, with a deliberately wedged gap geometry and engineered surface reflectivities, to produce an imaging spatial FTS. The Fabry-Perot interferometer can be much lighter and more compact than a conventional interferometer configuration, thereby making them suitable for portable and handheld applications. Both visible and long wave infrared (LWIR) spectral imagers have been demonstrated.

The LWIR version of the miniaturized Fabry-Perot has been shown to be effective for spectral imaging-based chemical detection applications. The compact LWIR spectral imager employs uncooled optics and a microbolometer camera; a handheld version is currently under development. The authors will summarize recent advancements and spectral imaging results associated with the spatial Fourier Transform imaging spectrometer system.

9101-38, Session 8

Adaptive hyperspectral imaging with a MEMS-based full-frame programmable spectral filter

David L. Graff, Steven P. Love, Los Alamos National Lab. (United States)

Rapidly programmable spatial light modulation devices based on MEMS technology have opened an exciting new arena in spectral imaging: rapidly reprogrammable, high spectral resolution, multi-band spectral filters that enable hyperspectral processing directly in the optical hardware of an imaging sensor. Implemented as a multiplexing spectral selector, a digital micro-mirror device (DMD) can independently choose or reject dozens or hundreds of spectral bands and present them simultaneously to an imaging sensor, forming a complete 2D image. The result is a high-speed, high-resolution, programmable spectral filter that gives the user complete control over the spectral content of the image formed at the sensor. This technology enables a wide variety of rapidly reprogrammable operational capabilities within the same sensor including broadband, color, false color, multispectral, hyperspectral and target specific, matched filter imaging. Of particular interest is the ability to implement target-specific hyperspectral matched filters directly into the optical train of the sensor, producing an image highlighting a target within a spectrally cluttered scene in real-time without further processing. By performing the hyperspectral image processing at the sensor, such a system can operate with little loss of performance, greatly reduced data volume, and at a fraction of the cost of traditional push broom hyperspectral instruments. Examples of color, false color and target-specific matched-filter images recorded with our visible-spectrum prototype will be displayed, and extensions to other spectral regions will be discussed.

9101-39, Session 8

Hyperspectral imaging by wavelength conversion

Nicolai H. Sanders, Jeppe S. Dam, Peter Tidemand-Lichtenberg, Christian Pedersen, Technical Univ. of Denmark (Denmark)

Today hyperspectral imaging can be realized by a variety of methods. A common need for these methods is highly sensitive infrared detectors. In this work we present an alternative method hereto where wavelength conversion is used to convert an image from the mid-infrared to near visible wavelength region followed by sensitive silicon based camera technology. Since wavelength conversion and silicon cameras are practically free from dark noise, even at room temperature, this combination provides an uncooled alternative for hyperspectral imaging in the mid-infrared. In practice, the infrared image is mixed with a 1064 nm intracavity continuous wave laser inside a MgO:LN crystal to generate an upconverted image at approximately 800 nm. However an important limitation is that the wavelength of the upconverted image is not the same throughout the image; each pixel in the upconverted image contains light from different wavelength intervals. To resolve this phenomenon we scan continuously or step-wise the phasematch condition so that a collection of images are recorded. By post processing these images can be recombined to obtain a new sequence of images only containing light from a narrow wavelength band, effectively providing hyperspectral imaging. We discuss how the spectral resolution is determined by the non-collinear phasematch condition and how many spectral elements that can be obtained by this method. In the present work we scan the phase match condition by translation of the object with respect to upconversion unit. Scanning could as well be done with a galvanometric scanner leading to higher frame rates than presented here.

9101-40, Session 8

Advancements in terahertz (THz) spectroscopy and imaging

David A. Heaps, Eiji Kato, Edward King, Richard McKay, Mark Sullivan, Xiao Hua Zhou, Akiyoshi Irisawa, Motoki Imamura, Advantest America, Inc. (United States)

Terahertz radiation has a high depth of penetration for many materials and can provide information on bulk properties, constituent composition, as well as, physical form and with the use of a pulse Terahertz source spatial distribution of components and sample layers. Different methods for narrowing the length of the Terahertz pulse have been investigated. The Cherenkov-type radiation emitter is what is going to be discussed in this presentation. A Cherenkov-type THz radiation emitter based on frequency conversion from a nonlinear crystal overcomes the output limitations caused by strong self-absorption in photoconductive antennas (PCA). We report here the development of a $LiNbO_3$ Cherenkov source with an exceedingly narrow pulse width of 146 fs and ultra-broadband THz spectral range of 0.5 to 7 THz (~16.7 to 233 cm^{-1}). The Cherenkov THz wave generation has efficiency improvements over the more commonly used PCA resulting in improvements in spectroscopic data collection. The Cherenkov THz pulse is narrower than the PCA pulse allowing for analysis of thinner layers in time-of-flight type measurements. A minimum of 10μm of silicon is measured in a layered silicon insulator chip with the Cherenkov source. In comparison, the PCA source was able to measure only to a thickness of 30μm.

Monday - Tuesday 5 –6 May 2014

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9102-1, Session 1

Image reconstruction method for non-synchronous THz signals

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Image reconstruction method for non-synchronous THz signals was developed by combining THz Free Electron Laser (THz-FEL) developed by Osaka University with THz imager. THz-FEL emits microsec order macro-pulses with repetition period of 100 msec, while THz imager has frame time of 33.473 msec with thermal time constant of 10s msec. The method employs a slight time-difference between the repetition period of THz pulses and three frames of THz imager, which is calculated to 0.418 msec. The ratio of the frame time to the time-difference, multiplied by a factor of 3, in other words, the number of consecutive frames, 240, corresponds to 2ϖ phase shift. This means that maximum signal extracted for each pixel out of the consecutive frames reconstructs correct image. This method was applied to obtain beam pattern of THz-FEL and found very effective. It was also applied to other pulsed THz source, where repetition period of THz pulse is 9.98 msec. The efficacy of the method was also proven. This method was finally applied to evaluation of time constants for pixels in 320x240 THz microbolometer array, using THz quantum cascade laser (QCL) with illumination period of 100 msec. A series of signals for illuminated pixel, obtained with consecutive frames, show exponential decay feature, from which time constants of 17-20 msec were obtained for five pixels. These values are consistent with the value obtained by a relation of microbolometer output to chopping frequency. Thus, the image reconstruction method developed here is found very effective.

9102-2, Session 1

Peculiarities of the detection and identification of substance at long distance

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Nowadays, the detection and identification of dangerous substances at long distance (several metres, for example) by using of THz pulse reflected from the object is an important problem. In this report we demonstrate possibility of THz signal measuring reflected from a flat metallic mirror placed about 3.5 metres from the parabolic mirror. Investigated object is placed before this mirror. Therefore, at present time our measurements contain features of both transmission and reflection modes. The reflecting mirror is used because of weak average power of used femtosecond laser.

In this mode of measurements we took measurements for a bag made from thick paperboard and contained various substances, many layers of thin papers (paper napkin for computer monitor), various clothes, plywood, newspaper, purse, bag and other materials. Measurements were provided at room temperature and humidity about 50%.

The aim of investigation was the detection of a substance in real condition. We discuss new features of the detection of a substance covered under various ordinary materials and possible way for their influence deleting on the detection using reflected THz pulse. In particular, it should be stressed that a spectrum of the measured signal is highly sensitive to an angle position of the flat mirror. Therefore, at long distance the position of object, that reflects the THz pulse, will influence essentially on the measured spectrum. Other very important features of the measurements with the multilayer of paper are the strong modulation of the spectrum of the reflected signal.

9102-3, Session 1

Subterahertz active imaging in transmission and reflection modes based on uncooled rectifying or bolometer type detectors

Aleksandr G. Golenkov, Igor O. Lysiuk, Anya V. Shevchik-Shekera, Fiodor F. Sizov, Zinovia F. Tsybrii, Vyacheslav V. Zabudsky, Vladimir A. Petriakov, Svetlana G. Bunchuk, Maria V. Apatskaya, Mariya I. Smoliy, Vladimir P. Reva, Sergei V. Korinets, V.E. Lashkaryov Institute of Semiconductor Physics (Ukraine)

Sub-terahertz (THz) active imaging system (~ 150 GHz frequency range) based on rectifying or hot electron bolometer types (HEB) uncooled detectors operating in transmission and reflection modes is developed. Using transmission and reflection modes one it can identify metallic parts of the objects. The images have shown well distinguishable boundaries between substances (metal, plastic, paper, liquid gas, air) and appeared due to its differences in absorption, reflection and optical thicknesses. Spatial resolution of the system is enough to recognize samples cavities with dimension of ~2 mm or more. The system consist of irradiation source (backward wave oscillator or Gunn diode with multiplication frequency), aspherical teflon lenses, two-coordinate mechanical scanner and direct detection terahertz detectors that were MCT (mercury cadmium telluride) HEB or long-channel Si-FET (silicon field effect transistors). The NEP (noise equivalent power) of bolometer or FET detectors was ~10 10 W/Hz. The spatial resolution of the images was ~1 mm, the dynamical range of registration system ~60 dB. The possible upper limits of responsivity and NEP of these detectors are estimated and it is shown that they can be used only in active regime in THz and sub-THz regions

9102-4, Session 1

Initial results of a real-time, quad-frequency band, polarization-sensitive THz line camera

Christoph A. Roedig, Don J. Burdette, Howard L. Mosbacker, Jeremy Law, Traycer Systems, Inc. (United States); Kubilay Sertel, Georgios Trichopoulos, The Ohio State Univ. (United States)

Many potential commercial applications to exploit the unique features of THz light still remains unfilled due to the lack of a cost-effective, real-time, large format THz camera capable of acquiring high-contrast images using conventional low-power, continuous-wave THz sources. Our team has recently realized a prototype device to fill this market need. The new sensor is composed of four, narrowband linear arrays, each sensitive to a single THz band. The initial model is tailored for low-noise detection at 220GHz, 320GHz, 420GHz, and 520GHz with better than 10 percent frequency bandwidth. Respective frequency bands feature 80, 120, 120 and 160 pixels closely packed with near diffraction limited pitch. Alternating antenna orientations allow the image to resolve the polarization of the received signal. Each pixel is composed of a narrowband antenna monolithically integrated and impedance matched to an antimonide-based heterostructure backward diode that is used to rectify the incident THz light into a DC voltage. Subsequently, the received signal at each pixel is amplified and digitized using custom electronics delivering frame-rates up to 60 kHz. Device performance metrics such as pixel responsivity and noise equivalent power, along with imaging relevant metrics (spatial resolution, image contrast, field-of-view, depth-of-field, etc.) will be presented for a representative non-destructive imaging application.

9102-5, Session 1

3D THz range finder of concealed objects

Aleksander Sešek, Janez Trontelj, Univ. of Ljubljana (Slovenia); Andrej Švigelj, Letrika Lab. d.o.o. (Slovenia)

Numerous applications require fast and accurate range measurement of the concealed object. As THz waves penetrate through almost all materials except metals, they are a candidate to perform this task. In this paper a system consisting of an illumination THz source and a THz detector array is presented.

A solid state 300GHz THz source signal is frequency modulated and guided to a detector array using a beam splitter. The detector array consists of the ultra sensitive bolometers with 1000V/W sensitivity and NEP of 5pW/√Hz. Their square law sensitivity allows mixing the reflected wave with the illumination wave resulting in a mixed product with a difference frequency of few kHz proportional to the target distance, the frequency modulation span and its rate. Parallel signal processing of all 16 signals results in fast range detection of the target. All 16 detectors provide 4 readings per second for all X and Y positions of the image.

A compact and portable system with 40GHz frequency modulated source provides $\Delta f/\Delta t$ = 160GHz/sec. This corresponds to 1kHz difference frequency per one meter distance of the target. Resolution accuracy in the micrometer range has been achieved using advanced signal processing.

In the paper the processing algorithms and the obtained results are presented and discussed. The complete hardware structure of the system is described together with the required signal processing procedures. The advantage of the presented system is that it operates at room temperature and is therefore cost effective and very robust.

9102-6, Session 1

Approaching real-time terahertz imaging using photo-induced reconfigurable aperture arrays

Md. Itrat Bin Shams, Zhenguo Jiang, Syed M. Rahman, Jubaid A. Qayyum, Huili G. Xing, Patrick Fay, Lei Liu, Univ. of Notre Dame (United States)

The submillimeter-wave and terahertz (THz) region has become increasingly more important to radio astronomy, chemical spectroscopy, bio-sensing, medical imaging, and especially security screening and defense. THz imaging devices and systems have been intensively studied and developed for all the above applications. Compared to other THz imaging techniques such as mechanical scanning and focal-plane arrays, coded-aperture imaging (CAI) offers the advantage of both high-performance (i.e., high SNR) and high speed as well as the potential for realizing simple and low-cost systems. We report room-temperature CAI approaching real-time performance in the WR-1.5 band (with a WR-1.5 VNA) using photo-induced reconfigurable aperture arrays. The coded aperture (based on Hadamard coding) was implemented using programmable illumination (an area of 2 cm x 2 cm) on Si wafer by a commercially-available digital light processing projector. Over the entire band of 500-750 GHz, each pixel can be optically turned on and off with an average modulation depth of ~15 dB and a modulation rate of ~1.3 kHz. Prototype demonstration has shown that a 4 x 4 image can be obtained in the order of seconds and this speed can be greatly improved for real-time and video-rate THz imaging. It has been demonstrated that a slowly moving object (~0.5 cm wide) was perfectly tracked in a video with image frames consisting of 8 x 8 pixels (2 cm x 2 cm). This photo-induced CAI has been successfully applied to mapping THz beams in a quasi-optical system, measuring THz zone-plates as well as characterizing micromachined THz horn antennas.

9102-7, Session 2

Tunable THz source based on nonlinear optical micro-ring resonator *(Invited Paper)*

Raju Sinha, Mustafa Karabiyik, Chowdhury G. Al-Amin, Phani Kiran Vabbina, Nezih Pala, Florida International Univ. (United States); Michael S. Shur, Rensselaer Polytechnic Institute (United States)

We theoretically investigated and designed a tunable, compact THz emitter in 1-10 THz range based on a nonlinear optical micro-ring resonator. The lack of tunable THz source operating at room temperature is still one of the major impediments for the applications of THz radiation. According to difference frequency generation (DFG) phenomenon, two narrowband laser beams of slightly different frequencies incident upon a noncentrosymmetric material produces an electromagnetic wave with the frequency equal to the difference between the two input frequencies.

The proposed device on an insulated SiO2 substrate consists of a nonlinear optical ring resonator on top of another ring waveguide capable of sustaining THz modes. A pair of Si optical waveguides is coupled to the nonlinear micro-ring in order to carry the two input optical waves. Another pair of Si THz waveguides is placed beneath the input optical waveguides to couple out the generated THz radiation from the ring to receiver antenna. Both optical and THz waveguides are engineered optimally with necessary effective mode indices in order to satisfy the phase matching condition. We presented the simulation results of our proposed device using a commercial FDTD simulation tool. We defined the optical nonlinearity by setting the X(2) value as 2.5x10^-17 F/V in the top ring. A distinguished THz peak coincident exactly with the theoretical calculations involving DFG is observed in frequency spectrum of electric field in the ring. Our device has the potential to enable tunable, compact THz emitters and on-chip integrated spectrometers.

9102-8, Session 2

10 aJ-level detection of ns pulse below 10 THz by frequency upconversion via DAST-DFG: more than a 4K bolometer

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Frequency upconversion has been proved to be quite promising for THz detection, which gains fast response, high sensitivity and ease of operation without requiring cryogenic cooling.

Recently, by resorting to DAST-DFG mechanism, we have achieved extremely sensitive THz detection via frequency upconversion. Pumped by ns green light, a dual KTP-OPO is used to generate THz waves by DFG mechanism via DAST crystal. For detection, a signal-KTP OPO supports flexible frequency tuning. At 4.3 THz, direct comparison has been implemented between 4K bolometer and upconversion detection. By using a simple PIN diode, frequency upconversion detection is one-order more sensitive than 4K bolometer for ns THz pulse detection. When applying an APD, it performs four-order better in terms of sensitivity. Power calibration has been implemented by using both a 4K bolometer with known responsivity and a calibrated pyrodetector (SPI-A-65 THz) with a set of THz attenuators, resorting to the is-TPG source. Results from the two approaches agree well and the minimum detectable pulse energy is in the order of 10 aJ, with a corresponding NEP of sub-pW/Hz1/2. By switching the two IR detectors, six-order dynamic range has been realized in current setup.

To the best of our knowledge, the obtained minimum detectable pulse energy and NEP implies the most sensitive detection of ns pulse above 1 THz by the frequency upconversion approach. However, improvement is still possible since we have not resorted to advanced photon counting technique yet. Various imaging/sensing applications are feasible in such a system.

9102-9, Session 2

Dynamic lithography of V-shaped antennas for beam steering applications

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A new technique to create metasurface for THz radiation is developed. The technique will be used to control propagation of the THz beam by means of non-mechanical beam steering. Within this technique, the Ti:Sa ultra-fast pulse laser tuned at wavelength of 800 nm is used for a dynamic lithography of metallic structures on a Si substrate. The dynamic lithography on Si substrate is performed with a liquid crystal spatial light modulator. The usage of spatial light modulator allows for imaging of sub-wavelength sized v-shaped antennas to structure the metasurfaces on the Si substrate. In the areas illuminated by images of v-shaped antennas on the silicon surface, electron-hole pairs are created which allows for appearance of metallic antennas of the metasurfase. Meanwhile, a THz beam is generated and directed to refract on the metasurfaces. The angle of refraction of the THz beam depends on the gradient of phase profile created by pattern of v-shaped antennas. The dynamic change of patterns of v-shaped antenna allows for beam steering. The THz beam is captured by a video camera designed and manufactured by INO (Canada).

9102-10, Session 3

THz plasmonic detection of high-intensity terahertz radiation *(Invited Paper)*

Michael S. Shur, Alexey Gutin, Rensselaer Polytechnic Institute (United States); Trond Ytterdal, Norwegian Institute of Technology (Norway); Sergey Rudin, Greg Rupper, U.S. Army Research Lab. (United States)

We investigated the response of the terahertz plasmonic InGaAs heterostructure field effect transistors (HFETs) to high intensity terahertz radiation. The experimental data show that the response at high intensities (large signal response) deviates from a quadratic detector response (small signal response) and is proportional to the square root of the terahertz beam intensity. Our simulation results (in the frame of the complete hydrodynamic model) link this transition from the small signal response to the large signal response to the development of plasma shock waves in the device channel. We also implemented the compact model of the plasmonic terahertz FETs in SPICE. The simulation results using the THz SPICE are in close agreement with experimental data and numerical simulations. This compact modeling approach allows us to investigate the effect of parasitic and external device impedances and extend our analysis to silicon CMOS and III-N HEMT plasmonic detectors.

9102-11, Session 3

Comparison of terahertz technologies for detection and identification of explosives

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We present results on the comparison of different THz technologies for the detection and identification for a variety of explosives from our laboratory tests under the same controlled conditions. The laboratory tests were carried out in the framework of NATO SET-193 “THz technology for stand-off detection of explosives: from laboratory spectroscopy to detection in the field”. The technologies we consider are THz spectroscopy based on broadband pulsed, narrowband pulsed and cw THz systems as well as electronic THz sources for 3D imaging applications. Experiments were carried out both in transmission and reflection geometry applying various barrier materials and include detection as well as identification of the substances under investigation. Aiming for a technological implementation of stand-off detection, we also make an assessment on the suitability of the various techniques for the field based on the results of our tests.

9102-12, Session 3

Terahertz properties YAG optical ceramics

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We report the optical and dielectric responses of fully dense optical ceramics of $Y_3Al_5O_{12}$ (YAG) between 0.5 and 4THz. These are compared to that of a single-crystal YAG sample. A set of twenty ceramic samples was prepared by solid-state sintering of Y_2O_3 and Al_2O_3 mixtures with compositions ranging from -0.62mol% to +0.96mol% of Y_2O_3 on each side of the garnet composition. After sintering, all samples are highly translucent in the visible region with attenuations better than 2 cm^{-1}. We also prepared samples covering the same compositional space following combustion syntheis and solid state sintering that yielded opaque samples. The samples were characterized using a time-domain spectroscopy system. All ceramic samples exhibit multiple weak resonances below 3.6 THz with amplitudes that depend on their composition. This is in contrast to the response from the single crystal samples. In addition, our experimental results show that the static permittivity goes through a minimum at the stoichiometric composition (e=10.83) and varies by more than 1% in this composition range. This trend is well reproduced by modeling. We will present these results and our interpretation.

9102-13, Session 3

High-resolution terahertz atmospheric water vapor continuum measurements

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The terahertz frequency regime is often used as the ‘chemical fingerprint’ region of the electromagnetic spectrum due to the many rotational and vibrational transitions of many molecules of interest. This region of the spectrum has particular utility for applications such as pollution monitoring and the detection of energetic chemicals using remote sensing over long path lengths through atmosphere. Although there has been much attention to atmospheric effects over narrow frequency windows, accurate measurements across a wide spectrum are lacking. The water vapor continuum absorption is an excess absorption that is unaccounted for in resonant line spectrum simulations. Currently a semi-empirical model is employed to account for this absorption, however more measurements are necessary to properly describe the continuum absorption in this region. Fourier Transform Spectroscopy measurements from previous work are

enhanced with high-resolution broadband measurements in the atmospheric transmission window at 1.5THz. The transmission of broadband terahertz radiation from 1.450-1.550THz through pure water vapor as well as air with varying relative humidity levels was recorded for multiple path lengths. The pure water vapor measurements provide accurate determination of the line broadening parameters. Also these measurements coupled with the atmospheric air measurements allow the water vapor continuum absorption to be independently identified at 1.5THz. Simulations from an atmospheric absorption model using parameters from the HITRAN database are compared with the current and previous experimental results.

9102-14, Session 4

Characterisation of graphene-based devices for THz Systems *(Invited Paper)*

Christos Themistos, Frederick Univ. (Cyprus); B. M. Azizur Rahman, City Univ. London (United Kingdom); Christos Markides, Frederick Univ. (Cyprus); Md. Uthman, A. Quadir, N. Kejalakshmy, City Univ. London (United Kingdom)

The Terahertz (THz) frequency region of the electromagnetic spectrum may be loosely defined between the 100GHz to the 30THz and offers a significant scientific and technological potential in many fields. Waveguiding in this intermediate spectral region remains a major challenge. The rapid growth in Terahertz technology has led to the development of a variety of devices such as photonic crystal fibers, quantum cascaded lasers, plasmonic waveguides, power splitters and narrow-band filters. Surface plasmon based research and recent studies have shown amongst the various THz waveguides suggested, the metal-clad waveguides supporting surface plasmon modes waves and specifically hollow core structures, coated with insulating material are showing the greatest promise as low-loss waveguides for their use in active components and as well as passive waveguides. Moreover, graphene based devices have attracted considerable attention, due to the unique optical properties of graphene at Terahertz frequencies. The H-field finite element method (FEM) based full-vector formulation is used to study the vectorial modal field properties and the complex propagation characteristics of Surface Plasmon modes of a hollow-core dielectric coated rectangular waveguide structures, and graphene based structures. Additionally, the finite difference time domain (FDTD) method is used to estimate the dispersion parameters and the propagation loss of such waveguides and devices.

9102-15, Session 4

Multiband terahertz quasi-optical balanced hot-electron mixers based on dual-polarization sinuous antennas

Zhenguo Jiang, Syed M. Rahman, Patrick Fay, Steven T. Ruggiero, Lei Liu, Univ. of Notre Dame (United States)

Receivers based on superconducting Hot-Electron Bolometers (HEBs) are widely used for terahertz (THz) sensing because of the advantages of high sensitivity, low noise, and low LO power requirement. Balanced HEB mixers are superior to single-element HEB mixers since the thermal noise and AM noise from the LO injection can be effectively suppressed. Although a 1.3 THz balanced waveguide HEB mixer has been reported, waveguide mixer configurations offer relatively narrow RF bandwidths. We report on the development, fabrication and characterization of a THz quasi-optical balanced superconducting HEB mixer utilizing a dual-polarization sinuous antenna that can potentially achieve both multiband operation and ultra-high sensitivity. In the balanced mixer configuration, a lens-coupled four-arm sinuous antenna was designed for operation from 0.2-1.0 THz with a nearly frequency-independent imbedding impedance of ~110 Ω. Two identical superconducting niobium HEB devices have been integrated at the antenna feedpoints, connecting each opposing pair of antenna arms to form a balanced mixer configuration. An air-bridge was also fabricated to separate the two mixer branches. The HEB devices were fabricated from 10 nm thick niobium film sputtered on semi-insulating silicon substrates. Each HEB device has dimensions of 80 nm ? 240 nm (3 squares) for approaching a resistance of 110 ? for impedance matching. In order to eventually achieve multiband mixer operation, tunable THz antenna elements with 50 GHz tuning range for reconfigurable mesh filters have been initially demonstrated in G-band. Mixer properties including antenna radiation patterns, broadband operation and polarization isolation have been characterized. Mixer performance including noise-temperature and conversion loss will soon be measured.

9102-16, Session 4

Wideband 220-GHz solid state power amplifier MMIC within minimal die size

Jerome Cheron, Erich N. Grossman, National Institute of Standards and Technology (United States)

The emergence of new technologies suitable at millimeterwave frequencies offers new opportunities for many wireless applications. Design of fully integrated MMIC transceiver is now practical at 220 GHz. Significant output power levels are necessary to overcome waveguide transition losses and attenuation due to the atmosphere. For this reason, a solid state power amplifier MMIC has been fabricated from a 250 nm InP HBT technology.

In order to integrate this power amplifier in a transceiver module, initial simulations showed that the width of the die must not exceed 300 μm to avoid multimode propagations due to the MMIC to waveguide transition up to 235 GHz. To respect this width, an 8-way power combiner and 4-way power combiners were designed. Each way combines 2-finger common base (CB) HBTs. The size of the compact power amplifier is 275x1840 μm2, including RF pads. From 213 GHz to 240 GHz, 14 dBm minimum output power associated with 16 dB of power gain were simulated.

Initially, studies on 6 μm emitter length (le) common emitter (CE) cells and 6 μm (le) (CB) cells were performed in order to select the appropriate topology. Simulations and measurements of these different cells have indicated the (CB) HBT provides significantly more gain. A 4 stages power amplifier was designed using (CB) HBTs. The output stage utilizes 16-finger (CB) HBTs in order to reach up to 17 dBm of output power around 220 GHz. Three driver stages, designed using 8-finger (CB) HBTs, are necessary to provide 20 dB of small signal gain over 10% of relative bandwidth.

9102-17, Session 5

Giant terahertz gain by excitation of surface plasmon polarities in optically pumped graphene *(Invited Paper)*

Taiichi Otsuji, Tohoku Univ (Japan)

This paper reviews recent advances toward new types of terahertz (THz) lasers using active plasmonics in graphene. Optical gain enabled by graphene ultrafast nonequilibrium carrier dynamics and phonon properties in the broadband THz frequency range might open the way to create the THz lasers, but has to compete against the strong losses in the THz range. Graphene plasmons, quanta of the collective charge density waves excited by two dimensional carriers in graphene, can dramatically enhance the light (THz photons) and matter (graphene) interaction, leading to “giant THz gain”. Recently, we have succeeded in observation of the giant THz gain in monolayer graphene pumped by a femtosecond infrared laser. This gain involves the following four processes: 1) graphene carrier population inversion by optical pumping, 2) stimulated interband THz photon emission by incident THz photons, 3) excitation of surface plasmon-polaritons (SPPs) and producing giant amplification of the THz SPPs, and 4) conversion of the SPPs to the THz photons yielding strongly amplified stimulated THz photon emission. The theoretical analysis predicted plasmonic THz lasing and superradiance in a planar periodic array of graphene plasmonic microcavities. This new mechanism is expected to enable new types of plasmonic THz lasers operating at room temperature.

9102-18, Session 5

Exploiting plasmonics for THz and infrared sensing *(Invited Paper)*

Stephen M. Hanham, Imperial College London (United Kingdom)

In the visible part of the electromagnetic spectrum there are practical and affordable technologies for spectroscopy applications which have been available for decades. Meanwhile, at longer wavelengths such as terahertz and mid-infrared, components and systems architectures are still emerging, offering new and complementary sensing modalities. Nevertheless, at those longer wavelengths, there is a significant scale mismatch between the interrogating wavelength and the targeted biological substance (e.g. bioliquids, molecules, etc.), imposing a limitation in terms of the smallest possible sample volume. We address this issue by exploiting the concepts of designer surface plasmon polaritons and localized plasmons.

Surface plasmon polaritons on flat metal surfaces lead to poorly confined Zenneck waves at terahertz frequencies, hindering the development of highly sensitive sensors based on surface modes. This obstacle can be overcome by texturizing the metal surface, e.g. corrugations or complementary split ring resonators. These engineered surface waves display two features that make them attractive for sensing applications: (i) they are very slow waves, leading to a long interaction times between the interrogating surface wave and the sample under test; (ii) they generate strong evanescent fields with subwavelength extension.

Alternatively, we have also exploited designer localized plasmons based on broadband gap micro-antennas and the lattice resonances that emerge when dipole antennas are arranged in an array. The broadband nature of the former approach allows multispectral surface-enhanced spectroscopy. Specifically, we demonstrate a broadband nanoantenna surface suitable for enhancing fluorescence, Raman spectroscopy, and direct mid-infrared absorption of biomolecules on the same chip.

9102-19, Session 5

Dispersion studies in THz plasmonic devices with cavities

Mustafa Karabiyik, Nezih Pala, Chowdhury G. Al-Amin, Raju Sinha, Florida International Univ. (United States)

Periodic structures are expected to yield plasmonic crystal modes with defined dispersion relations. To investigate the dispersion relation, we simulated the electric field distribution and absorption in HEMT devices with various geometries under THz radiation with varying incident momentum.

We simulated the dispersion relation for single channel multiple gate and multiple channel single gate HEMT devices. A cavity in plasmonic crystal is created by breaking the symmetry by changing the length of one of the gate width in grating gate devices in every n number of gates.

As the momentum increases toward the period of the unit cell, the asymmetrical modes are observed at different momentum and energy levels and the plasmonic bandgaps are observed for grating gate devices. Asymmetrical modes are the non-homogeneous charge distribution. When the momentum of the propagating mode is the same with the half momentum of the grating, a band gap opens up due to satisfaction of the Bragg condition for grating gate devices. There is no band gap observed for linearly integrated devices due to isolation of the cavities from each other. Localized cavity modes are created for plasmonic crystals. Cavity modes are observed with in the band gap of the plasmonic crystal.

9102-20, Session 5

Coherent phenomena in terahertz 2D plasmonic structures: strong coupling, plasmonic crystals, and induced transparency by coupling of localized modes *(Invited Paper)*

Gregory C. Dyer, Sandia National Labs. (United States); Gregory R. Aizin, Kingsborough Community College (United States); S. James Allen Jr., Univ. of California, Santa Barbara (United States); Albert D. Grine, Don Bethke, John L. Reno, Eric A. Shaner, Sandia National Labs. (United States)

The device applications of plasmonic systems such as graphene and two dimensional electron gases (2DEGs) in III-V heterostructures include terahertz detectors, mixers, oscillators and modulators. These two dimensional (2D) plasmonic systems are not only well-suited for device integration, but also enable the broad tunability of underdamped plasma excitations via an applied electric field. We present demonstrations of the coherent coupling of multiple voltage tuned GaAs/AlGaAs 2D plasmonic resonators under terahertz irradiation. By utilizing a plasmonic homodyne mixing mechanism to downconvert the near field of plasma waves to a DC signal, we directly detect the spectrum of coupled plasmonic micro-resonator structures at cryogenic temperatures.

The 2DEG in the studied devices can be interpreted as a plasmonic waveguide where multiple gate terminals control the 2DEG kinetic inductance. When the gate tuning of the 2DEG is spatially periodic, a one-dimensional finite plasmonic crystal forms. This results in a subwavelength structure, much like a metamaterial element, that nonetheless Bragg scatters plasma waves from a repeated crystal unit cell. A 50% in situ tuning of the plasmonic crystal band edges is observed. By introducing gate-controlled defects or simply terminating the lattice, localized states arise in the plasmonic crystal. Inherent asymmetries at the finite crystal boundaries produce an induced transparency-like phenomenon due to the coupling of defect modes and crystal surface states known as Tamm states. The demonstrated active control of coupled plasmonic resonators opens previously unexplored avenues for sensitive direct and heterodyne THz detection, planar metamaterials, and slow-light devices.

9102-21, Session Key

Terahertz signals for chemical and biological sensing and identification *(Keynote Presentation)*

Kiki Ikossi, Defense Threat Reduction Agency (United States)

Terahertz signals correspond to wavelengths that lie between optical-IR and mm-wavelengths offering an exceptional opportunity for sensing applications. Early results suggest that rotational and vibrational modes in molecules offer unique THz signals for spectroscopic identification of chemicals and biological molecules. The most resent approaches in THz spectroscopy have been made by extending the two ends of the spectrum, either from the optical systems or the electronic systems, into the THz region. In order to move the technology forward, it is evident by now, that new concepts and new methodologies need to be explored. This presentation will review the major scientific hurtles that need to be overcome and touch upon alternative scientific concepts that can be explored for THz sensing and identification.

9102-22, Session Key

Three-dimensional metamaterial devices functioning at terahertz frequencies *(Invited Paper)*

Weili Zhang, Oklahoma State Univ. (United States)

Quasi-three-dimensional invisibility cloaks, comprised of either homogeneous or inhomogeneous media, are experimentally demonstrated in the terahertz regime. Both the geometrical and spectroscopic signatures of a rectangular absorber placed under such a cloak were completely concealed. The inhomogeneous cloak was lithographically fabricated using a scalable Projection Microstereolithography process. The triangular cloaking structure has a total thickness of 4.4 mm, comprised of 220 layers of 20 μm thickness. The cloak operates at a broad frequency range between 0.3 and 0.6 THz, and is placed over an α-lactose monohydrate absorber with rectangular shape. Characterized using angular-resolved reflection terahertz time-domain spectroscopy, the results indicate that the terahertz invisibility cloak has successfully concealed both the geometrical and spectroscopic signatures of the absorber, making it undetectable to the observer. The homogeneous cloaking device made from birefringent crystalline sapphire features a large concealed volume, low loss, and broad bandwidth. It is capable of hiding objects with a dimension nearly an order of magnitude larger than that of its lithographic counterpart, but without involving complex and time-consuming cleanroom processing. The cloak device was made from two 20-mm-thick high-purity sapphire prisms. The cloaking region has a maximum height 1.75 mm with a volume of approximately 5% of the whole sample. The reflected TM beam from the cloak shows nearly the same profile as that reflected by a flat mirror.

9102-23, Session 6

Noncontact doping profile recognition in photovoltaic cells using terahertz time domain spectroscopy

Chih-Yu Jen, Christiaan Richter, Rochester Institute of Technology (United States)

We studied transmission mode terahertz time domain spectroscopy (THz-TDS) to recognize doping profile discrepancies in silicon for semiconductor and photovoltaic industry applications. The advantages of this technique are its fast measurement speed and the fact that it is non-destructive. The initial concept is proven by the use of several boron and phosphorus doping profiles on regular p-type semiconductor wafers. THz radiation, which has a strong interaction with free carriers, is expected to get more attenuation under higher implant dosages (more free carriers) corresponding to higher surface concentrations. The experimental result reveals that terahertz interactions with both electrons and holes are strong enough to recognize both N and P type doping profile changes. A reproducibility and repeatability test was done that indicates that the measurement variation is about 1.1%. Any profile variation that induced a change in THz radiation above this value can be detected. To prove the feasibility in photovoltaic cells we tested doped wafers (with emitter) from a commercial manufacturer and in-house fabricated wafers with comparable profiles. We demonstrated that doped wafers (emitters) can have the same four point probe reading but different measured THz radiation when the subsurface profiles differ. This suggests that THz technique has a superior ability to detect deviations compared to most commonly used metrology in the PV industry. THz radiation changes at various stages of solar cell production line are also investigated. We confirm that due to the long wavelength of THz radiation the typical texturing (scattering layer) do not impact the THz measurement.

9102-24, Session 6

T-ray detection in 0.35-um CMOS technology

Gregory J. Fertig, Chao Zhang, Zoran Ninkov, Rochester Institute of Technology (United States); Mark V. Bocko, Zeljko Ignjatovic, Judith L. Pipher, Craig W. McMurtry, Xi-Cheng Zhang, Univ. of Rochester (United States); J. Daniel Newman, Paul P. K. Lee, Andrew P. Sacco, Kenneth D. Fourspring, ITT Exelis (United States)

Interest in array imaging of terahertz energy (T-Rays) has gained traction lately, specifically CMOS based arrays due to their ease of manufacturability and the use of MOSFETs as a detection mechanism. 2D electron gas activity under terahertz radiation in the gate channel of a MOSFET can be related to plasmonic response waves which change the electron density and potential across the channel. The 0.35 μm silicon CMOS array used contains various MOSFET structures combined with differing antennae, providing a range of detectors to analyze. The effects of different MOSFET and antenna configurations, coupled with various operating parameters and modes are studied and results presented. A focus on single transistor-antenna testing provides a path for discovering the most efficient combination for coupling the 1.63 THz band energy. Test and evaluation results of a fabricated terahertz band focal plane array including sensitivity analysis and responsivity are described, in parallel with theoretical expectations of the plasmonic response in room temperature conditions.

9102-25, Session 6

THz imaging Si MOSFET device characterization

J. Daniel Newman, Paul P. K. Lee, Andrew P. Sacco, Kenneth D. Fourspring, ITT Exelis (United States); Mark V. Bocko, Zeljko Ignjatovic, Judith L. Pipher, Craig W. McMurtry, Xi-Cheng Zhang, Univ. of Rochester (United States); Chao Zhang, Zoran Ninkov, Rochester Institute of Technology (United States)

We present recent test and characterization results for a prototype, high pixel density, THz band Si MOSFET focal plane array (FPA). Our objective is to develop a best in class, low cost THz focal plane with on-chip correlated double sampling, gain and dark reference subtraction that will achieve BLIP limited imaging performance. The pathfinder THz chip is 24 x 24 element CMOS readout IC (ROIC) designed with 64 parametric variations in the circuit topology of the Si MOSFET, antennae variations both for narrow band bowtie and broad band spirals and the coupling impedance between the micro antennae and MOSFETS. Test results will provide the optimization of the final chip design. Detailed device modeling simulations of the plasmonic detection process including the interaction with the micro-antennae's with the MOSFET's are presented. Each pixel unit cell contains multiple individual THz band antennae that are coupled to independent amplifiers. The amplified signals are summed to improve detection SNR. The sensor is designed to operate at room temperature using passive or active illumination. In addition to the THz detector, a secondary array of Visible or SWIR context imaging pixels are inter-disposed in the same area matrix. Multiple VIS/SWIR context pixels can be fabricated within the THz pixel unit cell. This provides simultaneous, registered context imagery and "Pan sharpening" MTF enhancement for the THz image.

9102-26, Session 6

Radar cross section of frequency selective terahertz retroreflectors

Richard J. Williams, Andrew J. Gatesman, Robert H. Giles, Univ. of Massachusetts Lowell (United States); Williams E. Nixon, National Ground Intelligence Ctr. (United States)

The radar cross section of novel structures at terahertz frequencies is a rapidly advancing field with a growing list of applications and benefits. The radar cross section of spherical retroreflectors operating in the terahertz regime is investigated. The retroreflectors, also known as cat's eye retroreflectors, consisted of small silica spheres capped with a hemispherical reflective surface. Several retroreflectors with diameters ranging from 2mm to 8mm were fabricated and their RCS was experimentally measured at 100GHz, 160GHz, 240GHz, 350GHz, and 1.56THz. The diameter and frequency variation provided a comprehensive study of the backscatter phenomenology of this type of retroreflector at terahertz frequencies. Structures consisting of a two-dimensional array of identical retroreflectors were fabricated and similar RCS data collected. The RCS enhancement of this array was compared to a single spherical retroreflector. A frequency selective surface was applied to the retroreflector array demonstrating narrow-band retroreflective performance.

9102-27, Session 6

Broadband THz superlens grating

Chen Wang, Cheng Sun, Northwestern Univ. (United States)

The detection of chemical and biological species is by far the most promising application of THz spectrum. However, there are still significant challenges associated with extracting spectral information from target samples due to the weak absorption of the chemical and biological spectral signatures and strong dependence on the external environmental conditions. Recent developments in THz imaging spectroscopy have shown promise in addressing these issues. Specifically, an optimized sub-wavelength periodic grating was used to strongly enhance the THz-frequency transmission and the field coupling to biological materials. However, 1D grating with fixed width of the slot may only actively respond to excitation at certain wavelengths. In this work, a period trapezoidal array of InSb on flexible PDMS substrate is employed to achieve a broadband response in frequency band from 0.3 to 1 THz. The geometry of the trapezoid is optimized for an increased local electric field enhancement with TM incidence by rigorous coupled wave analysis (RCWA). The trapezoid has two bases 163μm and 326μm, respectively, periodicity 381μm, and thickness 4μm. This sub-wavelength trapezoidal grating shows a 10-20 fold increase in the electric field near the edges over the whole 0.3-1THz spectrum, indicating more than 100 times stronger radiation to the near field. The enhancement of the field extends through the grating structure and reaches peak values at the edges due to the discontinuity effect. The structure will be fabricated and measured to construct the broadband THz spectroscopy with superior detection sensitivity.

9102-28, Session Posters-Tuesday

Multispectral concealed weapon detection in visible, infrared, and terahertz

Marcin Kowalski, Mariusz Kastek, Henryk Polakowski, Norbert Palka, Marek Piszczek, Mieczyslaw Szustakowski, Military Univ. of Technology (Poland)

Detection of concealed dangerous objects is a very demanding problem of public safety. So far, the problem of detecting objects hidden under clothing was considered only in the case of airports but it is becoming more and more important for public places like metro stations, and government buildings.

The development of imaging devices and exploration of new spectral bands is a chance to introduce new equipment for assuring public safety. It has been proved that objects hidden under clothing can be detected and visualized using terahertz (THz) cameras. However, passive THz cameras still offer too low image resolution for objects recognition. On the other hand new infrared cameras offer sufficient parameters to detect objects covered with fabrics in some conditions, as well as high image quality and big pixel resolutions.

The purpose of the studies is to investigate the possibilities of using various cameras operating in different spectral ranges for detection of concealed objects. In the article, we present the measurement setup consisting of medium wavelength infrared (MWIR), long wavelength infrared (LWIR), THz and visible cameras and the initial results of measurements with various types of clothing and test objects.

9102-29, Session Posters-Tuesday

Advanced designs for non-imaging submillimeter-wave Winston cone concentrators

Andrew O. Nelson, Erich N. Grossman, National Institute of Standards and Technology (United States)

We describe the design and simulation of several non-imaging concentrators designed to couple submillimeter wavelength radiation from free space into highly overmoded, rectangular, WR-10 waveguide. Previous designs are altered to improve the uniformity of efficiency rather than the efficiency itself. The concentrators are intended for use as adapters between instruments using overmoded WR-10 waveguide as input or output and sources propagating through free space. Simulation and measurement show that the angular response is primarily determined by the Winston cone and is well predicted by geometric optics theory while the efficiencies are primarily determined by the transition section. Additionally, previous work has shown insensitivity to polarization, orientation and beam size. Several separate concentrator designs are studied, all of which use a Winston cone (also known as a compound parabolic concentrator) with an input diameter ranging from 4 mm to 16 mm, and "throat" diameters of less than 0.5 mm to 4 mm as the initial interface. The use of various length adiabatic circular-to-rectangular transition sections is investigated, along with the effect of an additional, 25 mm waveguide section designed to model the internal waveguide of the power meter. Adapters without a transition section and a rectangular Winston cone throat aperture are also studied. Adapters are analyzed in simulation for consistent efficiency across the opening aperture.

Conference 9103: Wireless Sensing, Localization, and Processing IX

Wednesday - Thursday 7 –8 May 2014

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9103-1, Session 1

Investigating the effects of digital filtering on digital modulations

John W. Nieto, Harris Corp. (United States)

Digital filters are typically used in digital communication systems to constrain the bandwidth of a transmitted signal on the transmit side and to remove unwanted noise at the receiving side. Filtering can have some unintended consequences on the performance of a communication system and this paper will investigate these consequences in an effort to aid waveform designers when selecting digital filters for their applications.

9103-2, Session 1

Demodulation improvement analysis of FEC quasi-coherent CPM

James A. Norris, John W. Nieto, Harris Corp. (United States)

Continuous Phase Modulation (CPM) schemes are advantageous for low-power radios. The constant envelope transmit signal is more efficient for both linear and non-linear amplifier architectures. A standard, coherent CPM receiver can take advantage of modulation memory and is more complex than a coherent Phase Shift Keyed receiver. But the CPM signal can be demodulated non-coherently and still take advantage of the trellis structure inherent in the modulation. With this complexity reduction, the CPM receiver is comparable in performance to a Phase Shift Keyed radio with the power utilization of a Frequency Shift-Keyed design. Recent analysis has discovered non-coherent demodulation techniques that can be applied to a CPM modulation that has been strengthened with forward error correction and that approach started to reach the performance of coherent CPM. This paper will provide an outline of demodulation techniques that further improve the bit error rate performance of coded CPM. Bit Error rate curves for specific variations of forward error correction and CPM modulation types will be presented. And some analysis of non-coherent soft decisions will be provided.

9103-3, Session 1

Performance analysis of MIMO multiuser DS-CDMA wireless communication systems under generalized receiver employment over Rayleigh fading channels

Vyacheslav P. Tuzlukov, Kyungpook National Univ. (Korea, Republic of)

In this paper, we carry out the performance analysis of MIMO multiuser DS-CDMA wireless communication systems over Rayleigh fading channels employing the generalized receiver (GR) constructed based on the generalized approach to signal processing in noise. The performance of space-time transmit diversity is examined over fast- and slow fading channels. The underlying space-time system employs N = 2 transmit antennas and M receive antennas at the mobile user and receiver base station, respectively. We consider the performance of the space-time multiuser system when using the GR to combat the effect of multiuser interference. In our analysis, we derive a closed-form expression for the probability of bit error for both fast- and slow-fading channels. These theoretical results are shown to be very accurate when compared to system simulations. Both simulations and theoretical results prove that, regardless of the system load, the full diversity order of 2NM for fast-fading channels and NM for slow-fading channels is always maintained, and only the signal-to-noise ratio (SNR) loss is incurred. This SNR loss is proved to be a function of only the number of users, i.e., level of interference, and independent of the number of transmit and/or receive antennas. Using our theoretical results, we show that the SNR loss from the single-user bound can be well approximated by 10 log(I/2), where I is the level of multiuser interference. GR implementation demonstrates superiority in comparison with employment of conventional receivers in MIMO multiuser DS-CDMA wireless communication systems over Rayleigh fading channels.

9103-4, Session 2

A cyber threat model for tactical radio networks

Michael T. Kurdziel, Harris Corp. (United States)

The shift to a full information-centric paradigm in the battlefield has allowed ConOps to be developed that are only possible using modern network communications systems. Securing these tactical networks without impacting their capabilities has been a challenge. Tactical networks with fixed infrastructure have similar vulnerabilities to their commercial counterparts (although they need to be secure against adversaries with greater capabilities, resources and motivation). However, networks with mobile infrastructure components and Mobile Adhoc networks (MANets) have additional unique vulnerabilities that must be considered. It is useful to examine tactical network based ConOps and use them to construct a threat model and baseline cyber security requirements for tactical networks with fixed infrastructure, mobile infrastructure and/or adhoc modes of operation. This paper will present an introduction to threat model assessment. A definition and detailed discussion of a tactical network threat model is also presented. Finally, the model is used to derive baseline requirements that can be used to design or evaluate a cyber security solution that can be scaled and adapted to the needs of specific deployments.

9103-5, Session 2

Node localization via analyzing multi-path signals in ultrasonic sensor networks

William J. Tomlinson Jr., Bo Dong, Stephan Lorenz, Subir Biswas, Michigan State Univ. (United States)

This paper proposes a novel signal analysis based node localization strategy for sensor networks used in structural health monitoring (SHM) applications. The key idea is to analyze location-dependent multi-path signal patterns in inter-node ultrasonic signals, and use machine-learning mechanisms to detect such patterns for accurate node localization on metal substrates on target structures. Majority of the traditional mechanisms rely on radio based Time Delay of Arrival (TDOA), coupled with multilateration, and multiple reference nodes. The proposed mechanism attempts to solve the localization problem in an ultrasonic sensor network (USN), avoiding the use of multiple reference beacon nodes. Instead, it relies on signal analysis and multi-path signature classification from a single reference node that periodically transmits ultrasonic localization beacons. The approach relies on a key observation that the ultrasonic signal received at any point on the structure from the reference node, is a superposition of the signals received on the direct path and through all possible multi-paths. It is hypothesized that if the location of the reference node and the substrate properties are known a-priori, it should be possible to train a receiver (source node), to identify its own location by observing the exact signature of the received signal. To validate this hypothesis, steps were taken to develop a TI MSP-430 based module for implementing a run-time system from a proposed architecture. Through extensive experimentation within an USN on the 2024 Aluminum substrate, it was demonstrated that localization accuracies up to 92% were achieved in the presence of varying spatial resolutions.

9103-6, Session 2

Wireless sensors in complex networks: study and performance evaluation of a new hybrid model

Peppino Fazio, Vincenzo Curia, Francesco Mirabelli, Univ. della Calabria (Italy); Miroslav Voznak, V?B-Technical Univ. of Ostrava (Czech Republic)

One approach for minimizing the digital divide in areas not covered by fiber cabling or telephone lines, or allowing to optimize the communication of any existing real network is modeling it in a kind of small-world network. Therefore, in this paper we propose a new modeling technique applied to Wireless Sensor Networks (WSNs). The modeling has the purpose of ensuring an improvement of the distributed communication, quantifying it in terms of clustering coefficient and average diameter of the entire network. The distributions of degree of individual nodes in the network will follow a logarithmic trend, meaning that the most of the nodes are not necessarily adjacent but, for each pair of them, there exists a path relatively short that connects them. The effectiveness of the proposed idea has been validated thorough a deep campaign of simulations.

9103-7, Session 2

SmartHome: a domotic framework based on smart sensing and actuator network to reduce energy wastes

Amilcare Francesco Santamaria, Domenico Falbo, Domenico Barletta, Floriano De Rango, Univ. della Calabria (Italy)

Domestic environment and human interaction with services supplied by domotic devices is being to be a very interesting application field. This application environment make possible a great interaction between humans, life environments and devices. The increasing of this interactions is the main goal of this work that can improve the classic concept of domotic to a new step giving to the static sensing and actions framework the intelligence to learn users habits and behaviors in order to make smart actions that can change dynamically in a real time way following inside and outside environments as well. This framework can be used for several fields of application including lightening, heating, conditioning, managing of water and energetic resources. The proposed system can optimize users consuptions giving the possibility to save money and to reduce the impact of energy consuptions to the earth environments matching the new “green” motto requirements. In this way, the overall system going towards the central concept of “internet of thing” where there are an overall intelligence that manage the objects making possible a more efficient way to produce, follow and manage domotic policies. Proposed framework bases its intelligence on several self-adapting algorithms that have the capacity to learn users’ behaviors and to change their outputs according to historical data and realtime happening as well. Each action is also driven by the even more key concepts of efficient energy use that mean economic bills saving.

9103-8, Session 2

Predicting impact of multi-paths on phase change in map-based vehicular ad hoc networks

Mark D. Rahmes, George Lemieux, Harris Corp. (United States); Jerome Sonnenberg, Harris Corp. GCSD (United States); David B. Chester, Harris Corp. (United States)

Dynamic Spectrum Access, which through its ability to adapt the operating frequency of a radio, is widely believed to be a solution to the limited spectrum problem. Mobile Ad Hoc Networks (MANETs) can extend high capacity mobile communications over large areas where fixed and tethered-mobile systems are not available. In one use case with high potential impact cognitive radio employs spectrum sensing to facilitate identification of allocated frequencies not currently accessed by their primary users. Primary users own the rights to radiate at a specific frequency and geographic location, secondary users opportunistically attempt to radiate at a specific frequency when the primary user is not using it. We quantify optimal signal detection in map based cognitive radio networks with multiple rapidly varying phase changes and multiple orthogonal signals. Doppler shift occurs due to reflection, scattering, and rapid vehicle movement. Path propagation as well as vehicle movement produces either constructive or destructive interference with the incident wave. Our signal detection algorithms can assist the Doppler spread compensation algorithm by deciding how many phase changes in signals are present in a selected band of interest. Additionally we can populate a spatial radio environment map (REM) database with known information that can be leveraged in an ad hoc network to facilitate Dynamic Spectrum Access. We show how topography can help predict the impact of multi-paths on phase change, as well as about the prediction from dense traffic areas. Utilization of high resolution geospatial data layers in RF propagation analysis is directly applicable.

9103-9, Session 2

Data analysis and integration of environmental sensors to meet human needs

Amilcare Francesco Santamaria, Domenico Barletta, Domenico Falbo, Floriano De Rango, Alessandro Imbrogno, Univ. della Calabria (Italy)

Nowadays one of the main task of technology is to make people’s life simpler and easier. Ambient intelligence is an emerging discipline that brings intelligence to our environments making them sensitive to us. This discipline has developed following the spread of sensors devices, sensor networks, pervasive computing and artificial intelligence. In this work we attempt to enhance the Internet of Thing with intelligence and awareness exploring various interactions between humans beings and the environment they are in. In particular, the core of the system is composed of an automation system which is made up with a domotic control unit and several sensors installed in the environment. The task of the sensors is to collect informations around the environment sending them to the control unit. Once the informations are collected the core combines them with those coming from Internet in order to establish meaning and picking up informations about human needs from them. The knowledge of the needs and the current environments status compose the inputs of the intelligence block, which has the main goals to find the right actions to satisfy human needs in a real time way. Moreover, the system is able to learn dynamically human habits and to understand their needs by an accurate speech recognition. In particular in this paper we mainly focused on definition and implementation of the algorithm that can deeply understand the distinctive characteristic of the speaker (sex, age, emotional state, etc.), the context of the speech, the ontology and the semantic of any conversation in the environment.

9103-10, Session 3

A low complexity approach for spread OFDM signal detection

Ali A. Elghariani, Michael D. Zoltowski, Purdue Univ. (United States)

Spread OFDM is based on spreading data symbols across all OFDM subcarriers prior to modulation such that each subcarrier contains a linear combination of all data symbols. Thus, if several carriers are lost due to spectral null, it may still be possible to recover all the transmitted symbols [1] , [2]. This is in contrast to the traditional OFDM where the symbol is lost if the carrier modulating it was nulled by the channel. This technique was introduced to improve the frequency diversity of the OFDM system which in turn leads to an improvement in the MIMO-OFDM system

In this paper, unique combination of signal processing procedures is introduced to provide a low complexity receiver with improved performance compared to linear Minimum Mean Square Error (MMSE) receiver. Soft output MMSE is implemented first to identify the most and the least reliable

bit positions using approximated Log Likelihood Ratio (LLR) information. The most reliable bits are deemed correctly received and the unreliable bits undergo Branch and Bound (BB) detection process in a sequential manner. Within this block of unreliable bits, BB starts with the most unreliable bits and then the second most unreliable bits and so on. Simulation results show that the proposed technique provides improved performance with a significant reduction in the computational complexity.

The advantage of this proposal is that it greatly reduces the complexity compared to the previous work because it uses the optimum detector only for the very noisy bits while the rest are detected using linear MMSE detector. If these noisy bits are large then this optimal detector is done in sequential steps to reduce the computations.

9103-12, Session 3

Improving BER in a MIMO free space optical communication system in a turbulence channel with spatial arrangement of the receiver array

Anjan K. Ghosh, Tripura Univ. (India); Digvijay Panchratna, Dhirubhai Ambani Institute of Information and Communication Technology (India)

Free space optical (FSO) communication offers a high speed, secure, unlicensed and low cost mode of communication and access. However, the efficacy of line-of-sight FSO communication in atmosphere is reduced by scintillation and scattering of the laser beam carrying the data signal. The use of multiple laser sources and multiple optical detectors, i.e., the MIMO technique, is popular for mitigating the adverse effects in a high data rate FSO system in a turbulence atmospheric channel with attenuation and fading. MIMO configurations take benefit from the spatial diversity and receive multiple independent copies of the same signal at the receiver, hence resulting in increased signal-to-noise ratio or BER.

In a MIMO FSO system the variation of the overall SNR and BER with parameters such as the number and the spatial arrangement of multiple transmitters and receivers in the diversity system are difficult to determine. In this paper we first consider a SIMO system with a single transmitter and multiple receivers with small apertures. A statistical model is developed for an OOK system considering atmospheric fading and misalignment factors between the spatially distributed receivers. Using both deterministic methods and Monte Carlo simulations we show that the number and the spatial arrangement of the receivers can be chosen so as to maximize the overall performance of the diversity system. Then the results are extended to a MIMO system to improve the overall performance even in the presence of attenuation and scintillation in the atmosphere.

9103-13, Session 3

MIMO space-time codes with decoding algorithm of low dimensionality

Xinjia Chen, Ernest L. Walker, Southern Univ. and A&M College (United States)

We propose a new structure of Space-Time codes of which the decoding problem can be decomposed into multiple one-dimensional closest-point search. The search can be accomplished by a simple rounding method. The new coding technique can be applied to data transmission of sensor systems, where the decoding task is expected to be quickly accomplished for the purpose of fast response.

9103-14, Session 4

DOA estimation exploiting coprime frequencies

Si Qin, Yimin D. Zhang, Moeness G. Amin, Villanova Univ. (United States)

Coprime array is an attractive structure to achieve sparse array configurations due to its simplicity and effectiveness. A coprime array utilizes a coprime pair of uniform linear subarrays, in which the respective interelement spacing is much larger than the unit spacing which is often half wavelength. Alternatively, effective coprime array configurations can be implemented using a uniform linear array (ULA) with two different sensing frequencies that hold a coprime relationship. This enables the integration of the coprime array and filter concepts, which were developed in the spectral or spatial domains. The joint spatio-spectral processing and representation provided by this array structure with coprime frequencies achieves high capabilities in meeting system performance and complexity constraints. Such joint-variable approach provides great flexibility in system design and offers the capability of on-the-fly reconfiguration, depending on the application environments. This paper examines the performance of the extended ULA configuration with coprime sensing frequencies when it is applied to direction-of-arrival (DOA) estimation. In particular, we analyze the number of detectable signals and the estimation accuracy as related to the array configuration and sensing frequencies.

9103-15, Session 4

Direction estimation, source location, and modulation detection for RF sources using steerable 3D IIR beam filters

Nilan Udayanga, Arjuna Madanayake, Chamith Wijenayake, The Univ. of Akron (United States)

The exact location and direction of transmission of far-field RF sources are important parameters in many decision making processes in defense situations. Several application areas such as military wireless networks, radar and cognitive radio (CR) environments rely on source location in order to achieve desired performance. Multidimensional signal processing techniques are a strong candidate to help accomplish such RF location/direction requirements because of certain advantages, such as very low complexity, compared to traditional phased arrays techniques.

Objective of this paper is to propose a new, real time RF source location and direction estimation system at the theoretical and simulation level. The proposed method uses 3-D infinite impulse response (IIR) beam filters and aperture beam forming techniques to help locate RF sources in the presence of high interference and jamming signals.

Several planar rectangular antenna arrays are required in the proposed approach. The arrays are located at different geographic locations with known separations. Each aperture can scan the 3-D space to resolve its direction of arrivals (DOA) over a wide band of RF range. Estimated angles of arrival in azimuthal and elevation planes together with known coordinates of the aperture lead to the calculation of locations. We propose detection methods such as cyclostationary feature detection for separating several RF transmitters having closely matching frequency channels and physical location.

The proposed RF location and waveform estimation method can eventually be implemented in real time object tracking systems and can be used to visualize the existing RF sources in realistic propagation environments.

9103-16, Session 4

Road safety alerting system with radar and GPS cooperation in a VANET environment

Amilcare Francesco Santamaria, Cesare Sottile, Floriano De Rango, Univ. della Calabria (Italy); Miroslav Voznak, V?B-Technical Univ. of Ostrava (Czech Republic)

New applications in wireless environments are increasing and keeping even more interests from the developer companies and researcher. In particular, in these last few years the government and institutional organization

for road safety spent a lot of resources and moneys to promote VANET technology, also car manufactories are giving a lot of contribution on this field as well. In our paper, we propose an innovative system to increase road safety matching the requests of the market to make possible a cooperation between onboard devices. The vehicles are equipped with On Board Unit (OBU) and with On Board Radar Unit (OBRU) which exploiting IEEE 802.11p standard can spread alerting messages around the network regarding warning and dangerous situations. Vehicles move along roads observing the environment, traffic and road conditions and vehicles parameters as well. These information can be elaborated and shared between neighbors and Road Side Unit (RSU) and, of course, with the Internet allowing inter-system communications. Radar systems have the task of detecting the environment that vehicles are passing through, as for example obstacles, road accidents, dangerous situations and so on. Once detected this information, through the use of the GPS receiver (equipped by the vehicles) will be recognized the exact location of the caught event and after an elaboration of data the informations is spread along the network. Once the drivers are advised they can make some precautional actions such as decreasing of traveling speed or modifing of current road path. In this work, the routing algorithm, which has the main goal to rapidly disseminate information are also been investigated.

9103-17, Session 4

Application of novel quasi-electrostatic sensor arrays for time based data collection and processing of supersonic, subsonic, and transonic revolving projectiles

Christopher J. Benfield, Wesley B. Williams, The Univ. of North Carolina at Charlotte (United States)

Sensors based on measuring the quasi-electrostatic field of traveling projectiles have been developed to detect the passage of a bullet in flight. These sensors provide an alternative to existing optical chronograph technologies, which are sensitive to variations in environmental lighting, and magnetic chronographs, which require close proximity to the bullet's path. In contrast these sensors are not sensitive to lighting changes and prior testing has demonstrated the ability to reliably detect bullets at ranges of at least 3 meters. A linear array of these sensors has been used to measure the time of flight between the sensors, which along with the known distance between the sensors can be used to calculate the projectile's velocity. These velocity measurements are compared to established chronograph technology as a measurement validation. By extending this array of sensors along the projected path of the projectile, a profile of the projectiles position and velocity through flight can be calculated. This expected utility of this data is in refining the calculations that are performed to determine a ballistic solution, particularly in long range engagements, where there has been limited availability of accurate projectile velocity measurements. This robust sensor array that can easily be deployed represents an inexpensive way to experimentally investigate numerous phenomenon related to ballistics modeling.

9103-23, Session 4

Entropy formulations for signal reconstruction from sensor arrays *(Invited Paper)*

Raghuveer Rao, U.S. Army Research Lab. (United States); Prudhvi Gurram, MBO Partners Inc. (United States)

Correlative interferometric imaging from sensor arrays relies on reconstructing source intensity by using the cross-correlation across near-field or far-field measurements from multiple sensors of the arrays. Often the reconstruction problem is ill-posed resulting in unrealistic reconstructions of signals and images. This paper examines the role that different entropy metrics can play in achieving various outcomes in the reconstruction process, ranging from improved resolution to inducing sparsity thus resulting in closer conformance of the reconstruction boundaries to the actual support of the signal source being reconstructed. Both near-field and far-field situations are considered and experimental results are provided.

9103-18, Session 5

Single source noise reduction of received HF audio: experimental study

Eric Campbell, Carlos O. Alva, Harris Corp. (United States)

This paper visits the applications and effects of single source noise reduction of clear voice audio on software defined radio transmissions. The audio input is sampled by a CODEC and processed by a DSP. The algorithm used is Harris patented technology currently used in vocoder noise reduction. The algorithm is adapted and applied to the operation of clear voice and analog voice security (AVS) to enhance the audio quality. The application of such noise reduction to enhance received audio is also investigated.

9103-19, Session 5

Smart sensing to drive real-time loads scheduling algorithm in a domotic architecture

Amilcare Francesco Santamaria, Floriano De Rango, Andrea Vaccaro, Pierfrancesco Raimondo, Univ. della Calabria (Italy)

Nowadays the focus on power consumption represent a very important factor regarding the reduction of power consumption with correlated costs and the environmental sustainability problems. Automatic load-based control on power consumption and life cycle represent the optimal solution for keeping costs low. The purpose of these systems is to modulate the power requests of electricity avoiding loads mismanagement by using intelligent techniques to manage them that are based on real time scheduling algorithms. The goal is to coordinate a set of electrical loads to optimize energy costs and consumptions based on the stipulated contract terms. The proposed algorithm use two new main notions: priority driven loads and smart scheduling loads. The priority driven loads can be turned off (stand by) according to a priority policy established by the user if the consumption exceed a defined threshold, on the contrary smart scheduling loads are scheduled in a particular way in order to keep their lifecycle and to safeguard the devices functionalities or allowing user to freely use the devices without the risk of exceeding the power threshold. The algorithm , using these two kind of notions and taking into account user requirements, manages loads activation and deactivation allowing the completion of their operation cycle without exceeding the consumption threshold in an off-peak time range according to the electricity fare. This kind of logic is inspired by industrial lean manufacturing which focus is to minimize any kind of power waste and to optimize the available resources.

9103-20, Session 5

A wireless time synchronized event control system

Robert Klug, Peter Scheffel, Jonathan Williams, McQ, Inc. (United States)

McQ has developed a wireless, time-synchronized, event control system to control, monitor, and record events with precise timing over large test sites for applications such as high speed rocket sled payload testing. Events of interest may include firing rocket motors and launch sleds, initiating flares, ejecting bombs, ejecting seats, triggering high speed cameras, measuring sled velocity, and triggering events based on a velocity window or other criteria. The system consists of Event Controllers, a Launch Controller, and a wireless network. The Event Controllers can be easily deployed at areas

of interest within the test site and maintain sub-100nanosecond timing accuracy for monitoring sensors, electronically triggering other equipment and event, and providing timing signals to other test equipment. Recorded data and status information is reported over the wireless network to a server and user interface. Over the wireless network, the user interface configures the system based on a user specified mission plan and provides real time command, control, and monitoring of the devices and data. An overview of the system, its features, performance, and potential uses is presented.

9103-21, Session 5

Distributive security mechanism for mobile cellular users in GSM cellular networks

Suresh K. Vashist, Maharshi Dayanand Univ., Rohtak (India)

Cellular communication across the world has become synonym to essential necessity in all walks of life globally. The cellular technology has also progressed leaps and bounds in last few decades right from Analog Mobile Personnel Services (AMPS) to 1G, 2G (GSM), 3G (UMTS) and 4G. Cellular subscriber's density has also increased in the similar ration. Various security features have been suggested by the researchers and implemented by the service providers of the cellular networks. However, with the use of cellular network by users for various more important fields like banking, defense, research and governance, it becomes pertinent to enhance the security features in distributive manner so as to give freedom to the users to choose the encryption key rather than keep dependence on service provider. The past precedence have shown the reluctance of GSM cellular service provider even to implement the A5/3 algorithm which is much rugged than A5/1 against eavesdropper and cloning, because it involves change in hardware and software in the existing network elements.

In the present paper we shall focus on Distributive Security Mechanism (DSM) to be provided to the users in the mobile handset instrument. This proposed mechanism will be seamless to the cellular network for the duration of the call. It will not put any extra financial burden on the service provider for the core network elements. The Mobile Handset (MH) user will have the privilege to choose the encryption key as per his/her choice. However, the MH unit manufacturers need to implement the proposed mechanism and they can pass on the additional expenses to the users. The methods of implementation of the mechanism and analysis of the effects have been carried out in the present paper.

9103-22, Session 5

Sensing technologies for monitoring and conservation of cultural heritage: wireless detection of decay factors

M. I. Martínez-Garrido, R. Fort, Instituto de Geociencias (Spain) and Campus Moncloa (Spain)

We provide a complete monitoring system by involving different sensing technologies as wireless sensor networks and other non destructive techniques to be used for heritage conservation applications and the study of decay phenomena. The implementation has been carried out in different and exigent architectural, archeological and natural heritage deployments as well as museums.

The communications quality of wireless sensor networks through characterization of the received signal and links is evaluated, together with reliability in measurement systems, sensor capabilities and energy consumptions which are analyzed for a long-term and low energy monitoring solution, taking into account processing data possibilities of these sensing techniques. The monitoring methodology via wireless sensing is also evaluated depending on software and hardware aspects for an appropriate validation and use in the heritage field.

9103-11,

Features and range of the FSO by use of the OFDM and QAM modulation in different atmospheric conditions

Andrej Liner, Jakub Jaros, Martin Papes, Petr Koudelka, Jan Latal, Jakub Cubik, Frantisek Perecar, Vladimír Vašinek, VŠB-Technical Univ. of Ostrava (Czech Republic)

The FSO (free space optics) communication uses the visible or infrared light for transmission. As well as cable optics FSO also uses laser for the data transmission, but the data flow is not transmitted in the fiber but in the air. This technology does not require expensive fiber optic cables and or ensure the licensing zone as it is in the case of radio networks. As well as in the cable transmissions are different modulations used. Nowadays, the most used modulations are QAM and OFDM. OFDM belongs to the border group of modulations with more carrier waves, where the information's are transmitted via subcarrier waves with lower data flow and baud rate. It is mainly used in broadband wire and wireless communications. OFDM provides very high signal resistance against the interference, chromatic dispersion and polarization mode dispersion. Modulation method involves the use of several hundreds to thousands of subcarrier waves. QAM is a composite modulation, which uses for symbol creation the combination of ASK (amplitude shift keying) and PSK (phase shift keying). Each state is represented by a specific value of the amplitude and phase. It's actually multistate modulation, which is able to transmit n bits by m symbols. That means that more bits are transferred at one moment. This paper deals with the modulations used in FSO. Most used modulations in FSO are OFDM and QAM. The main task was to determine how much is the reach of modulations changing with the changes of density (visibility) of fog and the set transceiver power. As software environment for simulations has been used Optisystem program. For the simulation of the atmosphere the FSO component has been used. In this component were simulated attenuations, which are responding to varying densities of fog. At different intensities of fog were changing the received power.

Conference 9104: Spectral Imaging Sensor Technologies: Innovation Driving Advanced Application Capabilities

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9104-1, Session 1

Small satellite sensor payloads: hyperspectral imaging implications for earth monitoring and remote sensing *(Invited Paper)*

David G. Goodenough, Univ. of Victoria (Canada)

The utilization of space-based hyperspectral imaging combined with other remote sensing techniques such as radar offer a unique and innovative ability to extract critical information addressing the needs of researchers and practitioners in the areas of earth monitoring, climate change, littoral zone ecology, forestry applications, and mining and exploration. To utilize this information and extract meaningful data products requires advanced imagery analysis capabilities and computing capabilities to fuse sensor data products.

9104-2, Session 1

SYSIPHE: focus on SIELETERS, the medium and longwave infrared spectral imaging instrument

Yann Ferrec, Christophe Coudrain, Sophie Thétas, Jérôme Primot, Laurent Rousset-Rouviere, Remi Gouyon, Marc Jacquart, Marcel Caes, Michel Tauvy, Sylvie Bernhardt, Joel R. Deschamps, Didier Henry, Alain P. Kattnig, Philippe Perrault, Gilles Le Coadou, Roland Domel, Patricia Cymbalista, ONERA (France)

Sysiphe is an airborne hyperspectral imaging sensor, result of a cooperation between France (Onera and DGA) and Norway (NEO and FFI). It is a unique system by its spatial sampling -0.5m with a 500m swath at a ground height of 2000m- combined with its wide spectral coverage -from 0.4µm to 11.5µm in the atmospheric transmission bands. Its infrared component, named Sieleters, consists of two high étendue imaging static Fourier transform spectrometers, one for the midwave infrared and one for the longwave infrared. These two imaging spectrometers have very close in design, since both are made of a Michelson interferometer, a refractive imaging system, and a large IRFPA (1016x440 pixels). Moreover, both are cooled at cryogenic temperature and mounted on their own stabilization platform which allows to both actively control and independently measure the line of sight. These data are useful to reconstruct and georeference the spectral image from the raw interferometric images. Sysiphe first flight occurred in September, 2013, and was fully successful. We will present the design of the Sieleters system, its laboratory characterization, and airborne experimental results

9104-3, Session 1

Optical design of wide swath hyperspectral imager

Yueming Wang, Shanghai Institute of Technical Physics (China); Jun-Wei Lang, Xizhong Xiao, Shanghai Institute of Technical Physics (China) and Univ. of Chinese Academy of Sciences (China); Zhikang Bao, Jianyu Wang, Shanghai Institute of Technical Physics (China)

Hyperspectral imaging technology was paid much attention for civil and military application during the past decade. It's very difficult to design and manufacture a wide swath hyperspectral imager. Fast optics and large format frame transfer detector are challenging in technology and costly in finance. Large format imaging spectrometers for future hyperspectral landsat mission was presented in 2011. The study is based on Raytheon's breadboard spectrometer technology and semi-modular FPA approach. The solution of NASA's HyspIRI is two large offner spectrometer with staggered slits and FPAs. Spectrometer with long image plane in Both future hyperspectral landsat mission of Raytheon and HyspIRI of NASA. The dimension of spectrometer is approximately proportional to the length of slit, on condition that definite image quality is given. For grating-type spectrometer, the lower groove density is needed in larger dimension spectrometer. The grating is expensive when the groove density is too low. Both single chip large format FPA and modular one are costly, especially for infrared hyperspectral system.

A wide swath hyperspectral optics based on field splitter and modular small offner spectrometer was presented in the paper. Parameters trade-off are given,such as F-number, pixel size, length of slit etc. The advantage of the optical design is small and modular spectrometers, FPA with standard format. The small dimension spectrometer for space application is low cost and immune to thermal stress and zero-gravity. FPA with standard format is also low cost and higher technology readiness level. The result of optical design with telescope and spectrometers is showed.

9104-4, Session 1

Development of co-boresighted Vis-NIR-SWIR hyperspectral imaging systems

Kwok-Keung Wong, Headwall Photonics Inc (United States)

Hyperspectral Imaging is used in many applications to identify or analyze materials in a scene based on the materials' spectral signatures. Unique features in the spectral signatures can span beyond the spectral range of the hyperspectral imager. Additionally, lighting conditions and other factors can adversely affect the quality of data. Expanding the spectral range of hyperspectral imaging systems can therefore improve the accuracy of object/material recognition/analysis by allowing the system to "see" more of the spectral signatures as well as expand the number of objects/materials in a scene that can be identified/analyzed. This is particularly important in applications where erroneous identification or analysis can result in substantial risk or cost.

More and more users are using two (or more) hyperspectral imagers to obtain different spectral ranges for their applications. Very few are effectively combining the data from the different hyperspectral imagers because it would require the hyperspectral imagers to be operated under tightly controlled conditions and the process of pixel co-registration is a very tedious and problematic post-processing step. In addition, this post-processing step prevents the use of the combined data in real-time applications.

This paper describes a co-boresighted Vis-NIR and SWIR hyperspectral imaging system which Headwall Photonics is currently developing. It integrates two hyperspectral imagers, each optimized for its respective spectral range, into a single system with real-time pixel co-registration resulting in a system capable of producing wide-spectrum hyperspectral images with high spectral resolution.

Aside from enabling real-time wide spectrum applications, such a system significantly simplifies the data acquisition and analysis for the user.

9104-5, Session 1

Lightweight airborne imaging spectrometer remote sensing system for mineral exploration in China

Taixia Wu, Lifu Zhang, Yi Cen, Jinnian Wang, Qingxi Tong, Institute of Remote Sensing and Digital Earth (China)

Imaging spectrometers provide the unique combination of both spatially contiguous spectra and spectrally contiguous images of the Earth's surface that allows spatial mapping of these minerals. One of the successful applications of imaging spectrometers remote sensing identified was geological mapping and mineral exploration. A light weight airborne imaging spectrometer system (LAISS) has been developed in China. The hardware of the compact LAISS include a VNIR imaging spectrometer, a SWIR imaging spectrometer, a high resolution camera and a position and attitude device. The weight of the system is less than 20kg. The VNIR imaging spectrometer measures incoming radiation in 344 contiguous spectral channels in the 437–902 nm wavelength range with spectral resolution of better than 5 nm and creates images of 464 pixels for a line of targets with a nominal instantaneous field of view (IFOV) of ~1 mrad. The SWIR imaging spectrometer measures incoming radiation in the 1000–2500 nm wavelength range with spectral resolution of better than 10 nm with a nominal instantaneous field of view (IFOV) of ~2 mrad. The 400 to 2500nm spectral range provides abundant information about many important Earth-surface minerals. An UAV carried flying experiment has been done in Ma'anshan iron mine, Anhui Province, China. The experiment results show the LAISS have achieved relative high performance levels in terms of signal to noise ratio and image quality. The potential applications for light weight airborne imaging spectrometer system in mineral exploration are tremendous.

9104-6, Session 1

Demosaicking for full motion video 9-band SWIR sensor

Andrey Kanaev, Mary R. Kutteruf, Michael K. Yetzbacher, U.S. Naval Research Lab. (United States); Michael J. DePrenger, Marjorie Rawhouser, Tekla Research Inc. (United States)

Short wave infrared (SWIR) spectral imaging systems are vital for Intelligence, Surveillance, and Reconnaissance (ISR) applications because of their abilities to autonomously detect targets and classify materials. Typically the spectral imagers are incapable of providing Full Motion Video because of their reliance on line scanning. We enable FMV capability for a SWIR multi-spectral camera by creating a repeating pattern of 3x3 spectral filters on a staring focal plane array (FPA). In this paper we present the imagery from FMV SWIR camera with nine discrete bands and discuss image processing algorithms necessary for its performance. The main task of image processing in this case is demosaicking of the spectral bands i.e. reconstructing full spectral images with original FPA resolution from spatially subsampled and incomplete spectral data acquired with the choice of filter array pattern. To the best of author's knowledge, the demosaicking algorithms for nine or more equally sampled bands have not been reported before. Moreover all existing algorithms developed for demosaicking visible color filter arrays with less than nine colors assume either certain relationship between the visible colors, which are not valid for SWIR imaging, or presence of one color band with higher sampling rate compared to the rest of the bands, which does not conforms to our spectral filter pattern. We will discuss and present results for two novel approaches to demosaicking: interpolation using multi-band edge information and application of multi-frame super-resolution to a single frame resolution enhancement of multi-spectral spatially multiplexed images.

9104-7, Session 2

Remote sensing: correlation of airborne hyperspectral and ground-truthing data

Brian Curtiss, Analytical Spectral Devices, Inc. (United States)

Spectral instrumentation for field, near-line, and on-line materials measurements can be effectively combined with airborne hyperspectral sensors to provide the scientific research community with a highly resolved, highly accurate representation of geological formations, meteorology conditions, and more. Correlating airborne hyperspectral data with ground-sampled data is a particularly beneficial exercise within the realm of 'ground truth' for remote sensing applications.

The paper will feature an overview of application areas where airborne and ground-truth meet, a discussion of the challenges users need to address, and a view toward where the technology is going.

9104-8, Session 2

Integration of UAVs and manned aircraft for future concept

Mustafa Özartan, Turkish Air Force Academy (Turkey)

The success of unmanned aerial vehicles (UAV) used by US forces in Bosnia, Afghanistan and Iraq signals a demand for wider use of these systems. In addition U.S. has gained many experiences. These experiences have detected advantages and disadvantages of the UAVs. Considering the advantageous aspects of UAVs, it is certain that UAVs plays and will go on playing an indispensable role in the future operational environment. However, eliminating and minimizing their disadvantages is very important for both users and humanity. In this work, the situational awareness in the process of decision making will be reassessed to decrease the faults of UAVs by creating an operating plan of the UAVs supported with manned aircraft.

9104-9, Session 2

Miniaturization of sub-meter resolution hyperspectral imagers on unmanned aerial systems

Samuel Hill, Headwall Photonics Inc. (United States)

Traditional airborne environmental monitoring has frequently deployed hyperspectral imaging as a leading tool for characterizing and analyzing a scene's critical spectrum-based signatures for applications in agriculture genomics and crop health, vegetation and mineral monitoring, and hazardous material detection. As the acceptance of hyperspectral evaluation grows in the airborne community, there has been a dramatic trend in moving the technology from use on mid-size aircraft to Unmanned Aerial Systems (UAS). The use of UAS accomplishes a number of goals including the reduction in cost to run multiple seasonal evaluations over smaller but highly valuable land-areas, the ability to use frequent data collections to make rapid decisions on land management, and the improvement of spatial resolution by flying at lower altitudes (<500 ft).

Despite this trend, there are several key parameters affecting the use of traditional hyperspectral instruments in UAS with payloads less than 10 lbs. where size, weight and power (SWAP) are critical to how high and how far a given UAS can fly. Additionally, on many of the light-weight UAS, users are frequently trying to capture data from one or more instruments to augment the hyperspectral data collection, thus reducing the amount of SWAP available to the hyperspectral instrumentation.

The following manuscript will provide an analysis on a newly-developed miniaturized hyperspectral imaging platform that provides full hyperspectral resolution and traditional hyperspectral capabilities without sacrificing performance to accommodate the decreasing SWAP of smaller and smaller UAS platforms.

9104-10, Session 2

Integration of spectral sensors onto multi-rotor UAVs: from Hollywood to remote sensing

Jeff Jackson, Infinite Jib Inc. (Canada)

Before 2006, it was unclear who was involved in developing Multirotor Unmanned Aerial Vehicles (UAV). In 2006, the German company MikroKopter built the first commercially available multirotor kits. The industry grew gradually and in 2012, started to expand worldwide. A year

later, the industry exploded, and a wide variety of craft, ranging from several hundred to tens of thousands of dollars, were available.

Multirotor craft development would not be possible without advancements in many areas of radio control (RC) and computerization. A remarkable feature of multirotors is that signals from a variety of sensors can be collected into a computer system; the computer system uses these signals to accurately control the power sent to propellers which keep the craft stable in the air. Once this science was mastered, the multirotor communities were quick to use this technology in cameras offering a unique point of view.

Over the past few years, major advancements in different aspects of craft design have made it possible for the multirotor craft to do a wide range of tasks and applications which would have been unheard of just a few years ago. In the presentation, I will discuss the parts of the multirotor and how they work in harmony to create a craft that can be balanced using the power of propellers. In 2013, the explosive growth in amateur multirotor development and Ready to Fly (RTF) hobby grade systems has brought the world's attention to these amazing craft.

Everywhere you turn - from TV shows to TV commercials - the multirotor is everywhere. Photographers and Cinematographers were the first to realize how useful multirotors could be. Everything from feature movies to your favorite Discovery Channel shows are now filmed using multirotor crafts. In 2014, multirotors will be used for industrial purposes. Industrial applications will grow significantly this year with numerous practical uses such as Photogrammetry, Infrared Imaging, Aerial LIDAR scans, and Hyper-spectral Imaging. Previously, Infinite Jib partnered with FLIR, a world leader in Infrared Sensors to create the world's first UAV to capture raw radiometric data. This year, Infinite Jib has partnered with a leading provider of advanced, miniaturized spectral imaging sensors to create the world's first multispectral UAV system for applications in agriculture, mineralogy, and physics.

In 2014, we expect to see more advancement in the multirotor world, with customers looking to increase the amount of weight the crafts can carry and the time that the craft can stay in the air. Infinite Jib is meeting those needs by offering new and innovative designs to remain a world leader in the production of ready-to-fly systems. Focus on parameters of Size, Weight, and Power, known as SWaP, that drive UAV payload performance will be addressed during this presentation.

9104-11, Session 3

Spectral imaging innovation: food safety and food quality applications

Moon S. Kim, Agricultural Research Service (United States)

No Abstract Available

9104-12, Session 3

Spectral imaging for cultural and historical preservation

Gregory Bearman, ANE Image (United States)

Over the last 20 years, spectral imaging has found a variety of applications, including cultural heritage. Broadly, this includes art, monuments, statues, buildings, ancient texts and books and even excavation archeological sites such as Angkor Watt or Caesarea. Spectral imaging has been used to read obscured texts, identify pigments in paintings and examine the under drawings of classic art. The decline in cost and increase in performance has made this tool more accessible to conservators and others in cultural heritage. Imaging beyond 1 micron creates an entirely new opportunity for chemical imaging, critical for this area. Recent work has focused on creating quantitative imaging for monitoring changes in cultural heritage, a key focus of conservators. Conservators cannot stop change and deterioration, only manage it. At the moment, they are lacking means to measure their objects. It is important to move from visualization and "pretty pictures" to real data that can be crunched. We will showcase some examples of spectral imaging applied to cultural heritage and show how calibrated quantitative spectral imaging provides important information for those responsible for the world's patrimony. In addition, we will lay out some future goals for hardware and software to make these tools easily available to conservators.

9104-13, Session 3

Utility of hyperspectral imagers in the mining industry: Italy's gypsum reserves

Janette H. Wilson, Headwall Photonics, Inc. (United States)

As world population increases and countries strive to market their natural resources for income, there is a need for the mining industry to adapt to the increased demand for both finished and unfinished product. The additional stress of safety concerns and negative environmental impacts involved with mining only adds to the complexity of the mining industry's problems.

Fortunately, hyperspectral technology as a means to facilitate solutions to these problems is becoming more and more affordable to commercial industry. Hyperspectral technology is applicable for mining in two key areas: (1) the mine and (2) the processing factory. In the mine setting, hyperspectral imagers are well-suited to aid in identifying components and their characteristics prior to mining as to increase efficiency and prioritization of material removal. Furthermore, in the case where material has similar visual characteristics, a quick hyperspectral image scan will allow the supervisors to determine the composition of the material to make on the spot decisions as to the suitability of composition and if mining should be started or stopped. Allowing for quick decision-making in the field has the potential to cut down on waste and man hours in mining undesirable material. In the factory setting, aside from the fact that the mined material should be better sorted prior to entering the factory, hyperspectral imagers can be used to further sort material based on its chemical signature, as well as other physical characteristics. Information obtained by the hyperspectral imager can be reduced to a signal that is sent to a mechanical sorter or robot which tells the machine what to do with the material, cutting down on the amount of in-line supervision required.

Evaporite deposits can be particularly tricky to mine due to the number of minerals present, varying hydration state, similarity in physical characteristics between minerals, the extent to which each mineral is mixed within an outcrop, etc. For this reason, it is helpful to assess the applicability of hyperspectral imaging in mining these types of deposits. This work employs two Headwall Photonics, Inc. hyperspectral imagers in the VNIR (400-1000 nm) and SWIR (950-2500 nm) spectral regions to characterize materials present for the production of sheetrock from a mine in Castellina Marittina, Italy. The information gained from this study shows that mineral samples thought to be gypsum, were misinterpreted. Through hyperspectral imaging, we were able to determine the proper components to be prioritized in the mining process.

9104-14, Session 3

Classification and identification of different level of aflatoxin B1 on maize kernels surface using infrared reflectance hyperspectral imaging

Wei Wang, China Agricultural Univ. (China); Kurt C. Lawrence, Seung-Chul Yoon, Gerald W. Heitschmidt, William R. Windham, Peggy Feldner, Agricultural Research Service (United States); Xuan Chu, China Agricultural Univ. (China)

A shortwave infrared (SWIR) hyperspectral imaging system with wavelength range between 1000 and 2500 nm was used to assess the potential to detect low levels of Aflatoxin B1 (AFB1) contaminants on the surface of healthy maize kernels. Three varieties of 450 kernels with 150 kernels for each variety were used to calibrate and validate the discrimination model, and another 150 kernels of the fourth variety were used as the independent test set samples. Four different AFB1 solutions were prepared and deposited

on clean kernel surfaces to achieve 120 samples of 10, 20, 100, and 500 ppb concentration, respectively. And a drop of 20 % methanol was dipped on the surface of 120 healthy kernels in the same way as AFB1 to get the control samples. Principal components analysis (PCA) was used to reduce the dimensionality of the spectral data, and then stepwise factorial discriminant analysis (FDA) was performed on latent variables provided by the PCA's, a 90% classification accuracy was achieved. Furthermore, some important wavelengths which represent the AFB1 were identified. The results indicated that hyperspectral imaging technology accompanied by a PCA-FDA method, can detect AFB1 that is applied directly on the maize surface.

9104-15, Session 3

Active gated imaging for automotive safety applications

Yoav Grauer, Ezri Sonn, BrightWay Vision Ltd. (Israel)

The paper presents Active Gated Imaging System (AGIS) in relation to the automotive field. AGIS is based on a fast gated camera and a pulsed Illuminator, synchronized in the time domain to record images of a certain range of interest which are then processed by computer vision real-time algorithms. In recent years we have learned the system parameters which are most beneficial to night time driving in terms of; field of view, illumination profile, resolution and processing power. AGIS provides also day-time imaging with additional capabilities which enhances computer vision safety applications. AGIS provides a good candidate for camera based Advanced Driver Assistance Systems (ADAS) and the path for autonomous driving in the coming future based on its outstanding low / high light level, harsh weather conditions capabilities and 3D potential growth capabilities.

9104-16, Session 4

Correction of scene turbulence and scene jitters by use of a dual port imaging Fourier-transform spectrometer

Louis M. Moreau, Florent M. Prel, Stéphane M. Lantagne, Claude B. Roy, ABB Analytical Measurement (Canada)

When the scene observed by an imaging Fourier-Transform Spectrometer is not stable in amplitude or in position during the time it takes to acquire to spectrum, spectro-radiometric errors are generated. These artifacts reduce the radiometric accuracy and may also damage the spectral line shape. The displacements of the scene in the field of view can be due to air turbulence, platform jitters or scene jitters.

We describe correction process based on the information provided by the second output port of a four-port imaging FTS. Corrected and uncorrected data will be compared.

9104-17, Session 4

Pulsed quantum cascade laser based hypertemporal real-time headspace measurements

Charles C. Harb, Toby K. Boyson, The Univ. of New South Wales (Australia); Thomas G. Spence, Loyola Univ. New Orleans (United States); David S. Moore, Los Alamos National Lab. (United States); David B. Arnone, David B. Caffey, Leigh J. Bromley, Daylight Solutions Inc. (United States)

Optical cavity enhancement is a highly desirable process to make sensitive direct-absorption spectroscopic measurements of unknown substances, such as explosives or illicit material. This paper reports advancements in the development of real-time cavity ringdown spectroscopy (CRDS) over a wide bandwidth using quantum cascade laser systems, with the aim to make headspace measurements of molecules at trace levels. We report results of two systems that measure nitromethane, acetonitrile, acetone, and nitroglycerin, where the spectra are obtained in less than four seconds and contain at least 150,000 spectral data points.

We demonstrate that CRDS may be applied to explosives detection with a simple instrument that is able to scan rapidly across a large spectral bandwidth. We are able to acquire orders of magnitude more spectral data points than previous CRDS experiments aimed at explosives detection, and to analyze them in a fraction of the time. We achieve noise equivalent detection limits on the order of ppb.

We show that sensitive measurements can be made at atmospheric pressure and temperature as provided an adequate laser wavelength range is selected. The systems can measure the headspace of a sample located in close proximity to the unit, or up to a few meters from it, ideal for measurement scenarios such as closed rooms or shipping containers. We also show that hypertemporal data can be gathered in real time, allowing the possibility for creating composite instruments such as gas chromatography combined with the real-time CRDS IR spectrometer to separate the headspace chemicals while measuring spectrum.

9104-18, Session 4

Discrete frequency infrared spectroscopic imaging with guided Fano resonators

Jui-Nung Liu, Matthew V. Schulmerich, Rohit Bhargava, Brian T. Cunningham, Univ. of Illinois at Urbana-Champaign (United States)

Fourier transform infrared (FT-IR) imaging spectrometers are almost universally used to record microspectroscopic imaging data in the mid-infrared (mid-IR) spectral region. While the commercial standard, interferometry necessitates collection of large spectral regions, requires a large data handling overhead for microscopic imaging and is slow. Here we demonstrate an approach for mid-IR spectroscopic imaging at selected discrete wavelengths using narrowband resonant filtering of a broadband thermal source, enabled by high-efficiency guided-mode Fano resonance in a one-layer subwavelength structured dielectric thin film on a glass substrate. The discrete frequency IR (DF-IR) approach is advantageous for microspectroscopic imaging applications in which only a handful of wavelengths are of interest for differentiation of image components, using a mechanically robust instrument. To demonstrate the approach, we perform DF-IR spectral imaging of a polymer USAF resolution target and human tissue in the C-H stretching region (2600-3300 cm-1). DF-IR spectroscopy and imaging can be generalized to other IR spectral regions and can serve as an analytical tool for environmental and biomedical applications.

Conference 9105: Thermosense: Thermal Infrared Applications XXXVI

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9105-1, Session 1

Infrared imaging of the e-beam melting 3D-printing process

Ralph B. Dinwiddie, Ryan R. Dehoff, Frederick A. List III, Larry E. Lowe, Kevin D. Harper, Oak Ridge National Lab. (United States)

This presentation will discuss how thermal imaging can be used to detect and characterize porosity in the e-beam based metallic 3D-printing process. Mid-wave IR cameras are used to map the temperatures and temperature gradients in the printed parts and powder bed during each build layer. The IR camera is also used to measure the emissivity of the as-printed metals and slightly sintered powder beds used in this research.

9105-2, Session 1

NIST emittance metrology in support of advanced manufacturing process control and modeling

Sergey N. Mekhontsev, Weston L. Tew, Leonard M. Hanssen, National Institute of Standards and Technology (United States)

The Optical Properties and Infrared Technology Group at the National Institute of Standards and Technology (NIST) has established a comprehensive program for infrared emittance determination of materials at elevated temperatures. Two approaches, based on direct emittance measurements, as well as indirect determination via reflectometry, are used and compared for mutual validation.

There are several modern technologies in the Advanced Manufacturing, which can benefit from better understanding of emissive properties of materials in solid, powder and liquid state. These involve directed energy techniques to selectively melt or sinter materials, such as laser and e-beam based additive manufacturing (AM), direct metal deposition and lamination, as well as laser drilling and welding.

We present a conceptual design for a dedicated facility at NIST to provide reliable data on radiative properties of metals, ceramics and polymers in the near and thermal infrared at temperatures up to 2000 K in vacuum or high purity purge, for dynamic conditions of a moving melt pool. The goal of this project is to serve the AM community's requirements via establishing material properties, dissemination of calibrated artifacts, and establishing a test bed for testing new methods and equipment in fully controlled conditions, close to manufacturing. The purpose of presentation is to inform and invite feedback from potential user community and potentially increase the impact on R&D in the advanced manufacturing domain.

9105-4, Session 1

Monitoring of industrial welding processes using high-speed uncooled MWIR imaging sensors

Rodrigo Linares Herrero, German Vergara, Raul Gutierrez Alvarez, Carlos Fernandez-Montojo, Maria Teresa Montojo Supervielle, Arturo Baldasano-Ramirez, Victor Villamayor, Luis J. Gómez, Maria Gonzalez, New Infrared Technologies, S.L. (Spain)

The paper is focused on the application of uncooled MWIR imaging sensors for the monitoring of industrial welding processes: resistance spot welding, resistance seam welding and laser welding. During the last 40 years, there has been little advancement in sensor systems for inline quality control monitoring of the welding process. Most of the existing systems are oriented for current, voltage and welding force monitoring. However, the temperatures reached during the majority of the welding processes lead to infrared sensing as a powerful tool, and to the MWIR band in particular as the most useful spectral band for monitoring this type of industrial processes. Infrared image information is a powerful tool to study the energy distribution in the HAZ (Heat Affected Zone).

The work presents some experimental results obtained with uncooled MWIR imaging sensors, by monitoring several welding processes. These results may be applied for real-time quality assurance of the process leading to better throughputs in industrial manufacturing. The high-speed capability of the sensors used helped also to characterize the dynamics of the welding process.

9105-5, Session 1

Infrared imaging of the polymer 3D-printing process

Ralph B. Dinwiddie, Lonnie J. Love, John C. Rowe, Oak Ridge National Lab. (United States)

This presentation will discuss how thermal imaging can improve the 3D-printing process. Both mid-wave and long-wave IR cameras are used to measure temperature gradients in the thermoplastic filaments as there are extruded from the printhead. The IR camera is also used to measure the emittance of the thermoplastic and transmission of IR windows used in this research.

9105-30, Session 1

Method for improving visualization of infrared images

Mario Cimbalista Jr., THERMOTRONICS (Brazil)

A coding process applicable to an original infrared image, generated from any value matrix, to change the infrared image into negative or inverted black and white and grey with the addition of specific split colors, causing a substantial difference in the way the retina and the brain processes the resultant images. The result obtained is a much less exhaustive way to see, identify and interpret infrared images generated by any infrared camera that uses this conversion process.

9105-6, Session 2

A study to investigate the inflammation inside the muscle using infrared thermography

Nicolas P. Avdelidis, Univ. of Thessaly (Greece) and National Technical Univ. of Athens (Greece); Chariklia K. Deli, Univ. of Thessaly (Greece); Panagiotis Theodorakeas, National Technical Univ. of Athens (Greece); Giannis Giakas, Athanasios Tsiokanos, Univ. of Thessaly (Greece); Maria Koui, National Technical Univ. of Athens (Greece); Athanasios Jamurtas, Univ. of Thessaly (Greece)

Unaccustomed eccentric exercise is associated with muscle damage, which is evidenced by a number of events that are manifested for several days after the initial muscle injury. Inflammation occurs due to eccentric exercise and plays a critical role in the degeneration and regeneration of the damaged muscle by triggering the acute phase response of the immune system and the removal of the damaged muscle tissue. The aim of this work was to investigate the potential of imprinting the intensity of the produced inflammation inside the muscle using infrared thermography. For this reason, four males and three females (20-30 year old) participated in the study. Thermographic images of the rectus femoris muscle were taken before, as well as 24, 48 and 72 hours immediately after an acute bout of

eccentric exercise (5 sets of 15 maximum repetitions). Eccentric exercise was performed with the one lower extremity, whereas the other lower extremity served as control.

9105-7, Session 2

Thermal camera used for the assessment of metabolism and functions of the rat brain

Mariusz Kastek, Tadeusz Piatkowski, Henryk Polakowski, Military Univ. of Technology (Poland); Zbigniew Czernicki, Ewa Kozniewska, Katarzyna Kaczmarska, Lukasz Przykaza, Mossakowski Medical Research Ctr. (Poland)

Motivation to undertake research on brain surface temperature in clinical practice is based on a strong conviction that the enormous progress in thermal imaging techniques and camera design has a great application potential. Intraoperative imaging of pathological changes and functionally important areas of the brain is not yet fully resolved in neurosurgery and remains a challenge. Extensive knowledge of the complex mechanisms controlling homeostasis (thermodynamic status of an organism being a part of it) and laws of physics (which are the foundations of thermography), make this method very good and a simple imaging tool in comparison with other modern techniques, such as computed tomography, magnetic resonance imaging and angiography.

Measurements of temperature distribution across the brain surface were performed on four rats (Wistar strain) weighing approximately 300 g each. Animals have remained under general anesthesia typically conducted using isoflurane. The brain was unveiled (the dura mater remained untouched) through the skin incision and removal of the bone cranial vault. Cerebrocortical microflow was measured using laser-Doppler flow meter. Arterial blood pressure was also measured in rat femoral artery. From the above data the cerebrovascular resistance index was calculated. Cerebral flow was modified by increasing the CO_2 concentration in the inspired air to 5% for the duration of 6 minutes. Another change in cerebral flow was induced by periodic closing of right middle cerebral artery. Artery occlusion was performed by introducing a filament for a period of 15 minutes, then an artery was opened again. Measurements were carried out before, during and after the artery occlusion. Paper presents results and methodology of measurements.

9105-8, Session 2

Intraoperative application of thermal camera for the assessment of during surgical resection or biopsy of human's brain tumors

Mariusz Kastek, Tadeusz Piatkowski, Henryk Polakowski, Military Univ. of Technology (Poland); Zbigniew Czernicki, Jacek Bogucki, Mossakowski Medical Research Ctr. (Poland); Marta Zebala, Medical Univ. of Warsaw (Poland); Katarzyna Kaczmarska, Mossakowski Medical Research Ctr. (Poland)

A study of temperature changes across cerebral cortex was performed for five patients with brain tumors (previously diagnosed using magnetic resonance or computed tomography) during surgical resection or biopsy of tumors. Measurements have shown that the temperature on the surface of the cyst was on average 2.6 K below the temperature of surrounding areas. It has been also observed that during devascularization of a tumor, i.e. cutting off its blood vessels, the tumor temperature lowers significantly in spite of using bipolar coagulation, which causes additional heat emission in the tissue. The results of the measurements are presented on the paper.

9105-31, Session 2

A combined approach for using thermography for the detection of diabetes mellitus

Bob Berry, Thermal Vision (Ireland)

This paper presents work done to develop an early diagnosis and monitoring method-encompassing thermography for the detection of Diabetes Mellitus. The early detection method involves fusion of images from infrared cameras, ultrasound devices, a 3d camera and a dermatascope. The project is to develop a novel system that could be easily used by physicians to allow for early intervention, and the paper highlights the approach taken by the Skindetector project.

9105-9, Session 3

Center crack detection during continuous casting of aluminum by laser ultrasonic measurements

Hubert Grün, Thomas Mitter, Jürgen Roither, RECENDT GmbH (Austria); Andreas Betz, Salar Bozorgi, AIT Austrian Institute of Technology GmbH (Austria); Peter Burgholzer, RECENDT GmbH (Austria)

Crack detection during continuous direct chill casting of aluminum is a matter of economics. Determining cracks during production process saves money, energy and raw material. Of course, a non-destructive method is required for this evaluation. Because of temperature concerns conventional ultrasound is not applicable. One non-contact alternative is laser ultrasonics. In laser ultrasonics short laser pulses (in the region of picoseconds to nanoseconds, in our case at a wavelength of 1064nm and 532nm) illuminates the sample. The electromagnetic energy gets absorbed at the surface of the sample and results in local heating followed by expansion. Thereby broadband ultrasonic waves are launched which propagate through the sample and get back reflected or scattered at interfaces (cracks, blowholes,...) like conventional ultrasonic waves. Therefore laser ultrasonics is an alternative thermal infrared technology. By using an interferometer also the detection of the ultrasonic waves at the sample surface is done in a remote manner. During preliminary examinations in the lab scanning different aluminum studs we were able to distinguish between studs with and without any cracks. We were even able to predict the dimension of the crack by evaluation the damping of the broadband ultrasonic waves. With simple image reconstruction methods we could localize the crack and give an estimation of the extent of the crack. Subsequent first measurements using this laser ultrasonic setup during the continuous casting of aluminum were carried out and showed the proof of principle in an industrial environment with elevated temperatures, dust, cooling water and vibrations.

9105-10, Session 3

Infrared imaging analysis of ballistic impacts of composite armor materials

Robert Furstenberg, Michael R. Papantonakis, Viet Nguyen, Christopher A. Kendziora, R. Andrew McGill, U.S. Naval Research Lab. (United States)

We report results on infrared imaging of composite armor panels subject to ballistic impacts from threats representative of shrapnel and rifle fire in an attempt to better understand mechanisms of energy dissipation within the panels. A liquid nitrogen-cooled long wave MCT infrared camera was used to acquire images at varying frame rates from 1600 Hz to 30 Hz to capture both the initial impact as well as the slow post-impact thermal relaxation. The integration time for each imaging segment was adjusted to match the dynamic range of the imaged scene with the well-capacity of the camera pixels to minimize noise equivalent temperature difference without pixel saturation. We discuss the calibration procedure and the need for multi-point calibration for imaging the initial impact. The infrared images are analyzed to estimate the thermal energy resulting from the projectile. Additionally, data from a high speed visible camera and post-impact high resolution computed tomography scans was used to estimate other channels of energy dissipation, including delamination and plastic deformation. The suitability of infrared imaging for performance characterization of armor panels is discussed.

9105-11, Session 3

Thermal inspection of composite honeycomb structures

Joseph N. Zalameda, F. Raymond Parker, Jeffrey P. Seebo, NASA Langley Research Ctr. (United States)

Composite honeycomb structures continue to be used widely in aerospace applications due to low weight and high strength requirements. Developing nondestructive evaluation (NDE) inspection methods is essential for their safe performance. Pulsed thermography is a commonly used technique for composite honeycomb structure inspections due to its large area and rapid inspection capability. Pulsed thermography is sensitive for detection of face sheet impact damage and skin to core disbond. Data processing techniques using principle component analysis to improve the defect contrast are presented. In addition, limitations to the thermal detection of the core are investigated. Other NDE techniques, such as ultrasound and computed tomography X-ray, are used for comparison to the thermography results.

9105-12, Session 3

Fiber orientation assessment on surface and beneath surface of carbon fiber reinforced composites using active infrared thermography

Henrique C. Fernandes, Xavier P. V. Maldague, Univ. Laval (Canada)

Composite materials are highly used in the industry. One of the reasons is because they have strength and stiffness comparable to metals with the added advantage of significant weight reduction. The fiber orientation, concentration and distribution have all a significant influence on the strength and stiffness of fiber reinforced composites. Thus, one needs to develop testing techniques to assess material's fiber orientation. Destructive methods can be employed to evaluate the fiber on a composite, e.g. cutting a section of the material, polishing the area and evaluating it with microscopy. However, the destructive approach is not always an option since the sample will be 'damaged' after the inspection and probably unfit for use. Thus, Non-Destructive Testing and Evaluation (NDT&E) techniques must be employed in some cases to assess the material's fiber content.
In this paper Infrared Thermography (IT) is used in order to assess fiber orientation of composite materials on the surface and beneath the surface of laminates made of carbon/PEEK (Polyether ether ketone) unidirectional prepreg. Specially, a modulated infrared diode laser beam is used to thermal stimulate a spot on the laminate's surface where the use different modulation frequencies allows to access fiber orientation on different depths. In the case of composite materials, which are thermal anisotropic, the thermal pattern formed on the surface of the material due to the thermal stimulation is an ellipse where its major axis orientation is related to the fiber orientation. During experiments the fiber orientation on the first and second layers were accurately measured.

9105-13, Session 4

Comparison of image processing techniques for the on-site evaluation of damaged frescoes

Paolo Bison, Alessandro Bortolin, Gianluca Cadelano, Giovanni Ferrarini, Consiglio Nazionale delle Ricerche (Italy); Fernando López, Univ. Federal de Santa Catarina (Brazil); Xavier P. V. Maldague, Univ. Laval (Canada)

Infrared thermography is a valuable tool for non-destructing evaluation of ancient artworks. Active thermographic techniques can be applied on-site thanks to their contactless and non-invasive nature. On-site monitoring could have some difficulties as the observed object could be difficult to reach and the properties of the analyzed materials are usually unknown. Moreover the availability of a site is typically very short and limited in time. For this reasons the acquired data are noisy or inhomogeneous and must be reorganized and post-processed with dedicated algorithms to enhance the analysis.

The frescoes of the San Gottardo Church, located in north-east of Italy, are showing multiple detachments due to the ageing process. More than 50 frescoed surfaces have been selected for the evaluation with an active thermography procedure. Each area has been heated with handheld air heaters and a sequence of infrared images of the cooling process has been recorded.

Several techniques are available for the post-processing of thermographic sequences; in this work standard algorithms such as Correlation, Principal Component Analysis (PCA) or modified algorithms based on sum and filtering are proposed and compared. The images are treated also with the Partial Least-Squares Thermography (PLST) method, a technique widely used in several science fields that has recently been introduced in the thermographic analysis showing good potential. The obtained results allowed to identify and locate the most important detachments on the surfaces.

9105-14, Session 4

heatWave: the next generation of thermography devices

Peyman Moghadam, Commonwealth Scientific and Industrial Research Organisation (Australia); Stephen Vidas, Queensland Univ. of Technology (Australia)

Energy sustainability is a major challenge of the 21st century. To reduce environmental impact, changes are required not only on the supply side of the energy chain by introducing renewable energy sources but also on the demand side by reducing energy usage and improving energy efficiency. Currently, 2D thermal imaging is used for energy auditing, in which captures the thermal radiation from the surfaces of objects and represents it as a colour-mapped images for energy efficiency monitoring. A limitation of such energy auditing is that they lack information on the geometry, location of objects with reference to each other, particularly across separate images. Such limitation prevents any quantitative analysis to be done for example to detect any changes before and after retrofitting.

To address these limitations, we have developed the next generation of thermography devices called HeatWave. HeatWave is a hand-held 3D thermography device that consists of a thermal camera, a range sensor and color camera to generate precise 3D model of objects with augmented temperature and visible information. As an operator holding the device smoothly wave his hands around the objects, HeatWave can continuously track its pose in space and integrate new information from the range and thermal and color cameras into a single, and precise 3D multispectral model. Information from multiple viewpoints can be incorporated into a single complete 3D multispectral model to improve accuracy, reliability and robustness of the global model. It is also possible to reduce any systematic errors in the thermal imaging acquired information.

9105-15, Session 6

Identification of soil erosion types in Nyaba River basin of Enugu State Southern Nigeria using remote sensing and geographical information system techniques

Virginia U. Okwu-Delunzu, Enugu State Univ. of Science and Technology (Nigeria)

This study presents possible way of soil erosion identification on a tropical watershed of Nyaba river basin in Enugu State using remote sensing and GIS techniques. The aim of this study is to identify and map out soil erosion types in Nyaba river basin and its spatial distribution status in 2011. This study identifies soil erosion types in Nyaba River Basin subcatchment units in Enugu Urban of Enugu State, Nigeria, which is a mountainous region with steep slope and an upland ecosystem. To achieve the aim of this study, data were collected from LandSat satellite image of 2011, rainfall data from NIMET for 2011, hydrological data and soil samples collected in the entire subcatchment unit. The data collected were processed using different methods; Erdas Imagine 9.1 was used in the Land use land cover image classification while the soil type was determine using Soil Textural Triangle by David Whiting, 2011 U.D.S.A , the hydrological data generated was analyzed using rational method formula in Microsoft Excel and were categorized into three classes: high, medium and low. The Spatial multi-criteria evaluation operation in Arc GIS 10 was used to generate the soil erosion map of the study area. The result showed that there were various erosion types in the study area. Erosion types identified by the research work are rill, sheet, and gully erosion. In conclusion, integrated Remote Sensing, Geographical Information System and Spatial Multi-criteria Evaluation Model tool used to identify soil erosion types in mountainous regions will assist decision makers in environmental management.

9105-16, Session 7

Rapid rotation invariant face detection and pose estimation in thermal infrared spectrum

Fang Hua, Stephanie Schuckers, Clarkson Univ. (United States)

Face detection has achieved high accuracy and efficiency in many visible spectral applications. Due to the differences of facial features between visible images and thermal images, face detector trained from visible facial features cannot achieve the expected performance in faces location in thermal images. In this paper, the problem of face detection in the thermal infrared spectrum is studied in order to understand the advantages and limitations of crucial steps for automatic and rapid facial analyzing system operated in day and night time. This paper presents a rotation invariant multi-view based face detection and pose estimation in thermal infrared spectrum.

The main contributions of this work are three-fold: First, a Haar feature based Multi-Level-Confidence (MLC) Adaboost classifier is proposed for providing information about the location and scale of each detected face in thermal infrared spectrum. In order to improve the detection rate, weak classifiers are built with a Multi-level Confidence strategy and boosted to construct the strong classifiers, avoiding the over-fitting problem by the Look-Up-Table (LUT) classifier.

Second, multi-view detectors of face images with pose angles between -90 degree and +90 degree are trained in sub-ranges and created separately in order to achieve the rotation invariant ability. These view-based detectors provide capabilities of face detection in 360-degree rotation-in-plane and 180-degree rotation-off-plane angles.

Third, a method of pose estimation is developed based on multi-view detectors and helped improving overall detection performances.

Experiments show our proposed method yields a high accuracy and rapid speed of thermal imaging based face detection and pose estimation in 15 frames per second video sequences with the image size of 640 x 480 pixels.

9105-17, Session 8

Pattern extraction and tracking on fast-moving objects in a binary IR thermal image

Chialun John Hu, SunnyFuture (United States)

If an uncooled IR camera is programmed to show the picture such that when an object point temperature T is above a certain temperature T1, the output image point is assigned color black. Otherwise if T is belowT1 the output image point is assigned color white. Then the output IR image is a binary image, in which, all high-temperature objects are displayed as black objects and all low temperature background objects are displayed as pure white background with all the background noises eliminated.

The author has derived a novel, super-fast image processing software to detect the boundary points of all these black objects embedded in the white background. Then the software will automatically calculate and assign a 36-dimension analog ID vector for each object bearing its unique boundary shape. This ID vector Vi for the i-th object can then be used as a tracking ID code for following each object when it moves, such that its moving path, moving speed and object orientation change can all be recorded automatically and numerically.

This is a super fast grouping and tracking scheme on fast moving objects, because the scanning on raw picture points is just a ONE-TIME linear scanning, not a combinatorial scanning like in conventional "clustering scanning."

Preliminary live computer experiments will be demonstrated.

9105-18, Session 8

The effect of a pre-lens aperture on the temperature range and image uniformity of microbolometer infrared cameras

Ralph B. Dinwiddie, Oak Ridge National Lab. (United States); Jonathan Grimm, Farragut High School (United States)

Recently a large number of uncooled radiometric microbolometer IR cameras have become available. These cameras are small, low cost, and light weight, making them excellent tools for predictive maintenance, process monitoring, building inspection, medical and veterinary applications. However, one drawback of these cameras is their limited temperature range. This paper explores the extension of the temperature range by placing an aperture in front of the lens. An aperture smaller than the lens will reduce the radiance to the sensor, allowing the camera to image targets much hotter than would normally be possible. These higher temperatures can be accurately measured by developing a correction factor to adjust the built-in temperature calibration. The effect of pre-lens apertures on the center-to-edge and center-to-corner signal levels will also be discussed.

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9105-19, Session 9

IR thermographic characterization of low energy impact damage in carbon/carbon composite by applying optical and ultrasonic stimulation

Vladimir P. Vavilov, Darya A. Derusova, Tomsk Polytechnic Univ. (Russian Federation)

Severity of impact damage depends on impact energy and velocity. While producing standard samples, a range of impact energy is typically from 10 to 400 J. The purpose of this study was to establish a relationship between

low energy impact (from 2 to 24 J) and some decision-making parameters in the inspection of 2-5 mm-thick carbon/carbon composites by using infrared (IR) thermography. Temperature acquisition was accomplished by using NEC TH-9100 and FLIR SC 7700 IR imagers. Both optical heating and ultrasonic stimulation techniques have been applied to excite samples under test with a sequence of IR images being recorded for some seconds. In the case of optical heating (Xenon and halogen lamps), temperature images which are vulnerable to noise have been converted into images of diffusivity based on the analysis of temperature evolution in time. An evident advantage of this approach is that uneven heating that is a notorious feature of Xenon flash tubes can be essentially suppressed due to the fact that time-domain parameters are less sensitive to both surface clutter and white noise than temperature-domain parameters. Besides, local values of diffusivity correlate well with energy of impact. Attempts to find a reliable correlation between impact energy and temperature patterns in the case of ultrasonic magnetostrictive stimulation has not proven to be successful because temperature signals strongly decay with growing distance from a point of stimulation (ultrasonic wave frequency has been 22 kHz, indentor electrical power ? up to 2 kW). However, this technique seems to be promising due to the «dark field» principle that provides power generation only within structural defects. Therefore, in general, the sensitivity of ultrasonic stimulation toward hidden defects seems to be the highest (to be characterized by a limit of about 2 J), although possible material damage in a simulated point still represents a problem.

9105-20, Session 9

Artificial neural network and active thermography for prediction of nonmetallic coating thickness

Hongjin Wang, Sheng-Jen Hsieh, Texas A&M Univ. (United States)

Non-destructive thickness measurement techniques, such as eddy current, magnetic, and ultrasonic methods, have difficulty measuring non-metallic coatings due to the properties of these materials. Current studies suggest that thermography-based measurements may provide a feasible solution for measuring the thickness of these types of coatings. The challenge in using current active thermography techniques is to determine how to reliably correlate a thermal profile obtained from an affordable IR camera with coating thickness. Artificial neural networks (ANN) have been used to model thermal profiles of a sample and then use this model to predict treatment responses in an unseen sample with reasonable success. However, limited work has found in using ANN models to predict treatment responses for samples that have not previously been seen by the ANN model.

The focus of this research is to build an ANN model to predict coating thickness using active thermography and thickness samples that have not previously been seen by the model. We use three different parameters—temperature over time, rate of temperature rise over time, and the derivative of a temperature increment's real part Laplace transform over the real axis—as inputs to three different ANN models to estimate coating thickness. The ANN model that uses the derivative of a temperature increment's real part Laplace transform over the real axis as the input yields 7.5% error. The model that uses temperature value over time yields an 8.5% error, and the model that uses rate of temperature rise yields 20% error rate. Six different algorithms—batch training with weight & bias learning rules, Powell -Beale conjugate gradient back-propagation, Bayesian regularization, gradient descent with momentum back-propagation, Levenberg-Marquardt back-propagation and Resilient back-propagation—were used in training the network. Results suggest that the gradient descent with momentum back-propagation algorithm yields a lower error rate than the other algorithms. We also varied the number of hidden nodes within the range from 10 to 20. Results suggest that 20 hidden nodes yields the lowest error rate. This finding suggests that having more hidden nodes in a model balances out the inherent noise within the input node data.

9105-21, Session 9

A hybrid frequency-spatial domain infrared image enhancement approach evaluated by fuzzy entropy

Qiong Zhang, Julien Fleuret, Xavier P. V. Maldague, Univ. Laval (Canada)

Traditional homomorphic enhancement method is only attributed to the frequency domain processing, which could not enhance the image outline effectively. A better homomorphic algorithm could consider the dynamic range of image to compress and expand gray levels of the target and thus enhance image details. After the frequency domain enhancement, the deployment of mathematical morphology could smooth the outline of the image in spatial domain. This paper develops a comprehensive approach to optimize the contrast of infrared image, utilizing non-linear filtering in frequency domain and top-hat and black-hat transforms in spatial domain. Besides, a fuzzy entropy function is defined to verify the proposed infrared image processing effects. Experimental results indicate that, through the proposed method, the image details and contours can be better improved comparing with other methods.

9105-22, Session 10

Pulse compression approach to digitized frequency modulated infrared imaging for nondestructive testing of carbon fibre reinforced polymers

Ravibabu Mulaveesala, Indian Institute of Technology, Ropar (India); Juned A. Siddiqui, Indian Institute of Information Technology (India); Vanita Arora, Indian Institute of Technology, Ropar (India); Amarnath Muniyappa, PDPM IIITDM Jabalpur (India)

InfraRed Thermal Wave Imaging (IRTWI) is one of the promising non-contact and full field inspection technique for non-destructive characterization. This technique relies on the mapping of surface temperature distribution to visualize the presence of surface and subsurface anomalies in the test material. Due to its fast and quantitative evaluation capabilities, IRTWI has gained significant importance in the characterization of Carbon Fiber Reinforced Polymers (CFRP). A CFRP specimen having flat bottom holes is considered for inspection using non-stationary Digitized Frequency Modulated Thermal Wave Imaging (DFMTWI) technique. Further depth scanning performance by using frequency domain based phase approach has been compared with recently proposed time domain phase approach.

9105-23, Session 10

On the application of a frequency identification technique on thermal data to identify defects in a material

Galid Arroud, Univ. Antwerpen (Belgium); Patrick Guillaume, Vrije Univ. Brussel (Belgium); Mahmoud El-Kafafy, Vrije Univ. Brussel (Belgium); Gunther Steenackers, Univ. Antwerpen (Belgium)

Using active InfraRed Thermography (IRT) as a detection technique to identify defects or flaws in a structure is beneficial due to its non-invasive character and the relatively large area detection. The post-processing of the recorded data is a phase that can't be underestimated, since interesting information about the structural integrity can be extracted in this phase. In most of the cases are the contrast images (proper to the classical approach of Pulse Thermography) or the phase images (peculiar to Pulse Phase Thermography) analyzed to identify material properties or to detect defects

in the structure. However, we want to introduce a third way to handle the data. That is creating a parameterized model for thermal data sets with the aim to identify material discontinuities. In this study we simulate the heat conduction (transient state) through a two-dimensional plate and use the simulation results as the thermal data set whereupon we will estimate a parameterized model by applying a frequency identification technique. This contribution describes the main concept of the approach and a clear comparison between a sound plate and a plate with a material discontinuity to illustrate the validity of the proposed approach.

9105-24, Session 10

Computational reduction of specimen noise to enable improved thermography characterization of flaws in graphite polymer composites

William P. Winfree, Patricia A. Howell, Joseph N. Zalameda, NASA Langley Research Ctr. (United States)

Flaw detection and characterization with thermographic techniques in graphite polymer composites are often limited by localized variations in the thermographic response. Variations in properties such as acceptable porosity, fiber volume content and surface polymer thickness result in variations in the thermal response that in general cause significant variations in the initial thermal response. These result in a "noise" floor that increases the difficulty of detecting and characterizing deeper flaws. A method is presented for computationally removing a significant amount of the "noise" from near surface porosity by diffusing the early time response, then subtracting it from subsequent responses. Composite thermal response simulations are utilized in defining the limitations of the technique. This method for reducing the data is shown to give considerable improvement characterizing both the size and depth of damage. Examples are shown for data acquired on specimens with fabricated delaminations and impact damage.

9105-25, Session 11

Survey of thermography in electronics inspection

Sheng-Jen Hsieh, Texas A&M Univ. (United States)

This paper reviews applications of infrared thermal signature techniques to detection of faults and defects on electronics boards. Issues essential to the successful application of infrared techniques to electronics manufacturing and circuit card maintenance are investigated. These issues include basic know-how such as scanning time interval and screening variables; a description of the types of defects and faults these methods have been used to detect; and a comparison of infrared thermal imaging and other detection means such as X-ray and functional testers. The paper concludes with a summary of potential problems and remedies. Future directions include design for infrared diagnosis and development of integrated testing techniques for detection and root-cause analysis.

9105-26, Session 11

Modelling and predicting hidden solder joint shape using parametric numerical analysis and active thermography

Jose Giron-Palomares, Zhejiang Univ. (China); Sheng-Jen Hsieh, Texas A&M Univ. (United States)

A methodology based on active infrared thermography to study and characterize hidden solder joint shapes on a multi cover PCB assembly was investigated. A numerical model was developed to simulate the active thermography methodology and was proven to determine the temperature within maximum errors of 3.21% (one cover) and 4.73% (two covers) and the grand average cooling rates with maximum errors of 8.85% (one cover) and 13.36% (two covers). A parametric analysis was performed by varying the number of covers, heat flux provided, and the amount of heating time. Temperature and grand average cooling rate distances among contiguous solder joint shapes, as well as solder joints discriminability, were determined to be directly proportional to heat flux, and inversely proportional to the number of covers and heating time. Finally, a mathematical model was developed to determine the appropriate total amount of energy needed to discriminate among hidden solder joints with a "good" discriminability for one and two covers, and a "regular" discriminability for up to five covers. The mathematical model was proven to predict the total amount of energy to achieve a "good" discriminability for one cover within a 10% of error with respect to the experimental active thermography model.

9105-27, Session 11

Nonstationary thermal wave imaging for nondestructive testing and evaluation

Ravibabu Mulaveesala, Vanita Arora, Indian Institute of Technology, Ropar (India); Juned A. Siddiqui, Indian Institute of Information Technology (India); Amarnath Muniyappa, PDPM IIITDM Jabalpur (India)

Among various widely used thermal non-destructive testing methods, non-stationary thermal non-destructive testing modalities have proved to be an indispensable approach for the inspection and evaluation of various materials. Growing concern of surface and subsurface defect detection capabilities with moderate peak power heat sources than the widely used conventional pulsed thermographic methods and in a reasonably less testing time compared to sinusoidal modulated lock-in thermography makes these non-stationary thermal imaging techniques finds their importance in this field. This present talk highlights a comparative study on different non-stationary thermographic techniques and their advantages and limitation. Experiments results for various non-stationary thermal imaging techniques are presented to find the defect detection ability of different excitation schemes and comparisons have been made by taking signal to noise ratio (SNR) into consideration.

9105-28, Session 11

Applications of infrared thermography for nondestructive testing of fatigue cracks in steel bridges

Takahide Sakagami, Kobe Univ. (Japan); Yui Izumi, Univ. of Shiga Prefecture (Japan); Sunao Kawabata, Yoshiaki Mizokami, Honshu-Shikoku Bridge Expressway Company Ltd. (Japan)

Applications of infrared thermography for nondestructive testing of fatigue cracks in steel bridges are presented. For screening detections of fatigue cracks in weld bead, temperature gap method based on thermal insulation at crack surfaces was effectively employed. Thermoelastic stress evaluation was conducted after screening. Stress distribution around crack tip was measured by infrared thermography, and structural integrity was evaluated from measured stress distribution.

9105-29, Session 11

Numerical approach to binary complementary Golay coded infrared thermal wave imaging

Ravibabu Mulaveesala, Indian Institute of Technology, Ropar (India); Amarnath Muniyappa, PDPM IIITDM Jabalpur (India); Juned A. Siddiqui, Indian Institute of Information Technology (India); Vanita Arora, Indian Institute of Technology, Ropar (India)

A novel binary complementary (Golay) coded infrared thermal non destructive testing and evaluation approach is introduced for characterization of low carbon steel sample having flat bottom holes as defects. The resultant correlation results of these individual Golay complementary codes used to reconstruct a short duration high peak power compressed pulse to extract the subsurface features hidden inside the test sample. In this paper, a finite element method has been used to model a low carbon steel sample containing flat bottom holes as sub-surface defects located at different depths. Results show the depth scanning capabilities of the proposed Golay complementary coded excitation scheme as a promising testing and evaluation method to detect the subsurface defects with improved resolution and sensitivity.

9106-1, Session 1

Compact remote optical system for real time measurement of fugitive aerosol emissions

Gregor A. Waldherr, Hai Lin, Michael T. V. Wylie, Hal Technology, LLC (United States)

Demonstrating particle matter (PM) emissions compliance with environmental regulations is required for operation of any industrial, commercial or military facility. Emission sources are initially screened based on the visible opacity via US EPA Method 9 standard. Nowadays, it is rather surprising that opacity is still visually determined by human eyes with smoke school training and annual certification. However, opacity alone doesn't reveal particle concentration and size distribution which is crucial to determine PM values. It would be desirable to have an automated, calibratable device to make such a measurement with higher accuracy and reliability and is not available to date.

We are developing a compact, hand portable system capable of quantitatively determining plume optical opacity in combination with possible particle concentration and size distribution (and hence PM) measurement for standoff distances up to 150 meters. The entire sensor package is anticipated to weigh less than 25 lb, and is tripod mountable. Our benchtop lidar-based system was built with a passively Q-switched Nd:YAG laser and optical receiver. We have demonstrated the feasibility of a remote-capable optical sensor system for real-time continuous monitoring of visible emission plumes and its effectiveness for quantitative opacity and possible PM measurement. We further report correlation and relationship of measured opacity and PM values designated by EPA.

The hand portable Remote Plume Particulate Matter (RPPM) meter that can determine opacity and PM load from remote fugitive PM sources will provide a regulatory compliance solution for visible emissions from fugitive sources for environmental studies, industrial and military applications.

9106-2, Session 1

Lidar applications: detection of flame

Gold R. D. Hood, Kevin Kochersberger, Virginia Polytechnic Institute and State Univ. (United States)

In order to improve wildfire management, additional sensor information is necessary. Real time collection and processing are essential to this application. Based on disaster management personnel interviews, terrain slope and flame height were most requested as benefiting from additional information. Terrain slope can be measured well in advance via Laser Infrared Detection and Ranging (Lidar). Flame height, on the other hand, needs real time collection and processing from a distant, as the height of flames and their ability to jump distances to ground crews is well correlated. Although lidar is frequently used in forestry, its primary purpose related to wild fire has been under the first aim: the collection of fuel package data in forested areas. In more adventurous cases, this active sensor has been paired with a CO2 so that it may detect the smoke rising above a wild fire and raise an appropriate alarm. More traditional applications include measuring line distances. Combining some of these utilizes, this paper shows that lidar can in fact be used to determine the presence of flame in low noise areas or areas that are pre-screened for comparison. Specifically, lidar can detect flame as a major distortion over a background layer. This also distortion provides clues about wind speed and flame region.

9106-3, Session 1

The Northwest Infrared (NWIR) gas-phase spectral database of industrial and environmental chemicals for in situ and remote sensing: recent updates

Carolyn S. Brauer, Timothy J. Johnson, Thomas A. Blake, Steven W. Sharpe, Robert L. Sams, Russell G. Tonkyn, Pacific Northwest National Lab. (United States)

With continuing improvements in both point- and remote-sensing techniques, there is an ongoing need for high-quality spectral databases. The Northwest Infrared Database (NWIR) contains quantitative, gas-phase infrared spectra of more than 500 pure chemical species that can be used for a variety of applications such as atmospheric monitoring, biomass burning studies, threat detection, etc. The data, recorded at 0.1 cm-1 resolution, are pressure broadened to one atmosphere (N2) in order to mimic atmospheric conditions. Each 296 K spectrum is a composite composed of a minimum of ten individual measurements. Recent updates to the database include over 60 molecules that are known or suspected biomass burning effluents. Examples from this set of measurements will be presented and experimental details will be discussed in the context of the utility of NWIR for remote observation.

9106-4, Session 2

Effect of film thickness on localized surface plasmon enhanced chemical sensor

Aschalew Kassu, Carlton W. Farley III, Anup Sharma, Alabama A&M Univ. (United States); Junpeng Guo, Wonkyu Kim, The Univ. of Alabama in Huntsville (United States)

A highly-sensitive, reliable, simple and inexpensive chemical detection and identification platform is demonstrated. The sensing technique is based on localized surface plasmon enhanced Raman scattering measurements from gold-coated highly-ordered symmetric nanoporous ceramic membranes fabricated from anodic aluminum oxide. To investigate the effects of the thickness of the sputter-coated gold films on the sensitivity of sensor, and optimize the performance of the substrates, the geometry of the nanopores and the film thicknesses are varied in the range of 30 nm to 120 nm. To characterize the sensing technique and the detection limits, surface enhanced Raman scatterings of low concentrations of a standard chemical adsorbed on the gold coated substrates are collected and analyzed. The morphology of the proposed substrates is characterized by atomic force microscopy and the optical properties including transmittance, reflectance and absorbance of each substrate are also investigated.

9106-5, Session 2

Comparison of plasmonic bioanalytical sensing platforms based on thin metallic layer, nanoparticles layer, or single nanoparticles

Jacqueline Jatschka, Ondrej Stranik, André Dathe, David Zopf, Andrea Csaki, Wolfgang Fritzsche, Institut für Photonische Technologien e.V. (Germany)

Noble metal nanoparticles are well known for their unique optical properties. By an external incident light beam, density oscillations of the nanoparticle's conduction electrons are induced at a specific frequency, which is known under the term Localized Surface Plasmon Resonance

(LSPR). This occurring resonance band can be adjusted by shape, size and material of the nanoparticle and influenced by changes of the local refractive index of the surrounding medium. This fact gives the opportunity to use noble metal nanoparticles as label-free bioanalytical sensors. Biomolecules can be bound directly on the nanoparticle's surface, which leads to a change of the local refractive index and a shift of the maximum peak detected by micro-spectroscopy.

A bioanalytical sensing platform for real-time measurements in-situ will be presented. Noble metal nanoparticles are immobilized on a glass substrate and implemented in a microfluidic chamber. Two different detection setups are compared one on the basis of a nanoparticle layer (eLSPR) and the other of single nanoparticles (sLSPR). The spectral information is detected in real time, which leads to an observation of binding kinetics of analytes. First, sensitivity determinations were carried out with ultra-thin (few nm thick) polymer layers, which were sequentially adsorbed on the nanoparticles by layer-by-layer deposition technique. The surface sensitivity and the volume sensitivity of different kind of nanoparticles e.g. spheres or peanuts with eLSPR and sLSPR will be presented and compared to simulations and the established SPR technique. Finally, the sensing of bioanalytes in form of detection of DNA hybridization will be presented.

9106-6, Session 2

Large area broad-band resonant substrate for surface-enhanced Raman scattering

Nan Zhang, Kai Liu, Haomin Song, Xie Zeng, Dengxin Ji, Qiaoqiang Gan, Univ. at Buffalo (United States)

SERS refers to a vibrational spectroscopy technique for the characterization of low concentration analytes bound to or near plasmonic surfaces. It has been widely used as a highly surface-sensitive and label-free analytical technique for chemical and biological sensing applications down to single molecule level. Although this technique has been commercialized based on microscopic Raman spectroscopy systems, substrates with localized enhanced electromagnetic field that can excite strong Raman scattering are required. In recent years, extensive research efforts have been focused on the development of inexpensive and large area SERS substrates with high enhancement factors, reproducible and uniform responses. Current dominant fabrication techniques include electron beam lithography, nanoimprint, self-assembled nanosphere, and hybrid nanoporous lithography methods, which are still relatively expensive and complicated to fabricate high quality SERS substrates over large areas. To overcome these limitations, we report a simple and cost-effective method to manufacture large-scale three-layered super absorptive SERS substrates using direct sputtering deposition. By controlling the deposition and post thermal treatment conditions, random metallic nanoparticles can be formed simply on a diverse range of substrates to function as the nanoantennas supporting strongly enhanced localized plasmon modes. Due to the randomly distributed dimension of these nanoantennas, a broadband plasmonic absorption resonance can be obtained, which generates strong enhancement of the excitation and Raman scattered signal simultaneously. Using this substrate, we achieved a high area-average EF of 8.2 ? 10^6 and excellent uniformity with only 14.5% variation simultaneously over the entire sample area, which is better than many commercial SERS substrates.

9106-7, Session 2

Plasmonic chip for chemical and biological sensing *(Invited Paper)*

Hoan Thanh Ngo, Andrew M. Fales, Tuan Vo-Dinh, Duke Univ. (United States)

No Abstract Available

9106-8, Session 3

Hyperspectral domains and methods for chemical detection in ambient environment *(Invited Paper)*

George G. He, EOIR Technologies (United States)

No Abstract Available

9106-9, Session 3

Active (quantum cascade lasers) and passive (FTIR) infrared spectroscopy for detection of environmental threats *(Invited Paper)*

Erik R. Deutsch, Petros Kotidis, Anish K. Goyal, Block Engineering, Inc. (United States)

No Abstract Available

9106-10, Session 3

Pigment identification in pictorial layers by hyperspectral imaging

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The use of hyperspectral imaging (HSI) as a diagnostic tool in the field of cultural heritage is of great interest and it presents high potentialities, being this analysis non-destructive, non-invasive and portable. Furthermore, the possibility to couple hyperspectral data with chemometric techniques allows to get qualitative and/or quantitative information on the nature and physical-chemical characteristics of the investigated materials. A study was carried out to explore the possibilities offered by this approach to identify pigments in paintings when different wavelength ranges are investigated. More in detail, six pigments have been selected, they have been then mixed with four different binders and applied to two different supports: wood and canvas. The resulting reference samples were acquired by HSI in the VIS-NIR (400-1000 nm) and SWIR (1000-2500 nm) wavelength ranges. Data were processed adopting a chemometric approach based on the PLS_Toolbox (Version 6.5.1, Eigenvector Research, Inc.) running inside Matlab® (Version 7.11.1, The Mathworks, Inc.). The aim of the study was to verify, according to the information acquired in the two different wavelength regions, the correlation existing between collected spectral signatures and sample characteristics related to the different pigments, binders and supports utilized. Results were very good showing as correlations exist. New scenarios can thus be envisaged for analysis, characterization, conservation and restoration of paintings, considering that the developed approach allows to obtain, just "in one shot", information, not only on the type of pigment, but also on the utilized binder and support.

9106-11, Session 3

Combustion of materials and chemical using standoff infrared hyperspectral imaging

Marc-André Gagnon, Vincent Farley, Pierre Tremblay, Simon Savary, Martin Chamberland, Telops (Canada)

Combustions of materials and chemicals are challenging systems to characterize due to the variability and the potential hazardous nature of the emission gases. Depending on the type of combustion and chemical nature of the combustible, a complex mixture of oxidation products, by-products,

as well as thermal decomposition products can be expected. Many of these combustion gases are infrared-active species which possess a unique spectral infrared signature. The combustion of sulfur-rich coal, sulfur-depleted coal, ammonium sulfate and ammonium nitrate was characterized using a longwave (LW, 8-12 μm) and midwave (MW, 3-5 μm) Telops Hyper-Cam, commercially available standoff infrared hyperspectral imaging sensors. The selectivity provided by high-resolution infrared hyperspectral imaging allows time-resolve imaging of various gases like carbon monoxide (CO), carbon dioxide (CO2), sulfur dioxide (SO2) and nitrous oxide (N2O). The relationship between the type of combustible and the combustion gases illustrates the usefulness of standoff infrared hyperspectral imaging for characterizing the combustion of materials and chemicals.

9106-12, Session 3

Automatic detection and classification of EOL-concrete and resulting recovered products by hyperspectral imaging

Roberta Palmieri, Giuseppe Bonifazi, Silvia Serranti, Univ. degli Studi di Roma La Sapienza (Italy)

The possibility to develop an efficient recovery and reuse of end-of-life (EOL) concrete represents one of the main targets applied to EOL buildings and/or civil constructions dismantling/recycling. The need to recycle EOL concrete materials dramatically increased in these last years. The reason being linked to: i) the lower availability of steady supplies of natural aggregates, ii) the need to secure ample supplies of concrete aggregates to the construction industry and, finally, iii) the environmental constraints more and more limiting the DW wastes disposal. EOL concrete recycling thus can represent a valid alternative to increase aggregates availability allowing to reach, at the same time, other important benefits as: i) a reduced exploitation of new resources, ii) the utilisation of recovered materials, otherwise land filled, iii) a reduction of transport and energy costs and iv) a lower overall environmental impact. To be this approach a real alternative to classical natural resources exploitation, it is required that the entire processing chain, from EOL concrete structure dismantling to EOL-concrete processing, is handled minimising costs and maximising output products values, that is producing "certified" materials able to really replace the natural ones. The fulfilment of these goals passes through the definition and set up of innovative procedures finalised to collect and model information on concrete characteristics before demolition and to define the composition of particles as resulting from comminution/classification/separation actions. This latter aspect being finalised to identify both recovered coarse aggregates characteristics (i.e. particles composition: aggregate/cement ratio and textural assessment), and presence of contaminants (i.e. bricks, gypsum, steel, glass, plastics, wood, etc.). In this paper a new technology, based on HyperSpectral Imaging (HSI) sensing devices, and related detection architectures, is presented and discussed in order to define and apply simple to use, reliable, robust and low cost strategies finalised to define and implement innovative smart detection engines for a preliminary EOL-concrete characterisation/modelling and for a further recovered aggregates flow stream quality control (i.e. aggregates liberation and contaminants detection) finalised to recovered materials and/or products certification. The proposed sensing architecture is fast, accurate, affordable and it can strongly contribute to bring down the economic threshold above which recycling is cost efficient.

9106-13, Session 4

LPG humidity sensor using double overlay

R. S. Kaler, Thapar Univ. (India); Nidhi Chandel, Central Scientific Instruments Organisation (India) and Thapar Univ. (India); Pawan Kapur, Central Scientific Instruments Organisation (India)

In this paper, we have reported long period fiber grating sensor probe for relative humidity monitoring using double overlay..Firstly, a thin overlay of metal oxide (ITO) was deposited on LPG by using dip coating methodology. Similarly a combination of hygroscopic material(Gelatin & cobalt chloride) was deposited onto ITO layer. Field emission scanning electron microscope (FESEM) has provided detailed evidence of attachment of the amalgamation on LPG. Surface modification is evident in FESEM image. It is also clear that the technique used for the coating produce uniform and nicely adhered thin film layer. The experiential set up comprises of a humidity chamber to create precise and controlled level of %RH. A broadband light was connected to one end of the coated LPG and the other to an OSA with level resolution 0.01dBm and wavelength resolution of 0.1nm to monitor the transmission spectrum of coated LPG sensor with respect to different levels of applied %RH. The demonstrated sensor can be to measure RH variation efficiently in the range of 40% to 95% RH with sensitivity of 0.12 nm/ % RH, accuracy of 98.45% and stability error 0.031%. We have also investigated hysteresis, repeatability the sensor exhibited a hysteresis error of ±0.12%RH, repeatability of 98.7% and response time 24secs.

9106-14, Session 4

Polarization resolved angular optical scattering of aerosol particles

Brandon Redding, Yale Univ. (United States); Yongle Pan, U.S. Army Research Lab. (United States); Hui Cao, Yale Univ. (United States)

Real-time detection and identification of bio-aerosol particles are crucial for the protection against chemical and biological agents. The strong elastic light scattering properties of airborne particles provides a natural means for rapid, non-invasive aerosol characterization. Recent theoretical predictions suggested that variations in the polarization dependent angular scattering cross section could provide an efficient means of classifying different airborne particles. In particular, the polarization dependent scattering cross section of aggregate particles is expected to depend on the shape of the primary particles. In order to experimentally validate this prediction, we built a high throughput sampling system, capable of measuring the polarization resolved angular scattering cross section of individual aerosol particles flowing through an interrogating volume with a single shot laser pulse. We calibrated the system by comparing the polarization dependent scattering cross section of individual polystyrene spheres with that predicted by Mie theory. We then used the system to study five particles types: Polystyrene aggregates composed of 1 μm and 500 nm spheres, Bacillus subtilis (BG, Anthrax simulant) spores, Arizona road dust, and tryptophan molecules. We found that the polarization resolved scattering cross section depends on the shape of the constituent elements of the aggregates. This work indicates that the polarization resolved scattering cross section could be used for rapid discrimination between different bio-aerosol particles.

9106-15, Session 4

Near-infrared spectroscopy and pattern-recognition processing for classifying wines of two Italian provinces

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The promotion of wines with a unique geographical connotation is considered a strategic factor for protecting and boosting the European share of the wine market. Labels bearing denomination of origin (PDO) and geographical indication (PGI) trademarks are often used to highlight the peculiarities of wines, for better visibility to consumers and differentiations with respect to similar products with lower price.

Beside analytical techniques suitable for laboratory use only, optical spectroscopy has emerged as a rapid and non-destructive tool for quick

measurements. In fact, the entire spectrum from the ultraviolet to the mid-infrared is capable to highlighting even minimal differences between wines. Spectroscopic data are usually processed by means of multivariate data analysis, demonstrating that the combination of spectroscopy and chemometrics provides as a modern and straightforward tool for wine classification and authentication.

This paper presents an experiment which was carried out in the near-infrared band only for distinguishing the wines produced in two close provinces of the Abruzzi region of Italy. A collection of 32 wines was considered, 18 of which produced in the province of Chieti, while the other 14 coming from the province of Teramo. They were red, rosè and white wines of different varieties such as Sangiovese, Montepulciano, Chardonney, Malvasia, Pecorino, Melot, and Cerasuolo.

A conventional dual-beam spectrophotometer was used for measurements in the 1200-1900 nm spectroscopic range, which showed the most significant differences among the various samples. The Principal Component Analysis (PCA), which is one of the most popular and powerful technique for data dimensionality reduction and quick object classification, was used for patter-recognition processing. Classification maps in the PC1-PC2 or PC2-PC3 spaces were obtained, both successfully grouping the wine samples in two distinct clusters, corresponding to Chieti and Teramo provinces, respectively.

9106-16, Session 5

Microfluidics for analytical applications: from etching to 3D printing

R. Shatford, S. Eshaque, Vassili Karanassios, Univ. of Waterloo (Canada)

Microfluidics has been receiving significant attention in chemical analysis applications. In terms of fabrication technology, microfluidic channels have been fabricated using technologies ranging from wet chemical etching to deep reactive ion etching. More recently, 3d-printing has been employed to make microfluidic channels for applications ranging from microplasma channels, to channels used for bio-analytical applications, to vacuum pumps on a chip and from there on to chemical synthesis on chips and more recently, to fabricate for chemical synthesis. In this presentation, fabrication technology will be briefly reviewed and these applications will be evaluated using examples from the author's research.

9106-17, Session 5

Temperature-stable low-power ring oscillator design for ASIC applications

Hossein Jafarian, Ali Daneshkhah, Sudhir Shrestha, Mangilal Agarwal, Maher E. Rizkalla, Kody Varahramyan, Indiana Univ.-Purdue Univ. Indianapolis (United States)

A temperature-stable, low-power ring oscillator design with a wide tuning range implemented in an ASIC is presented. The design uses a new arrangement of chain delay elements which consists of a current-starved inverter and a CMOS capacitor. The delay is controlled by changing the current through the delay elements. The simulation results show that the frequency of the presented oscillator is stable against ambient temperature variations, with less than 0.5% deviation in frequency when the temperature was changed from 0 to 50°C. However, the oscillation frequency was highly sensitive to the control voltage (sensitivity ~10 mV) with a wide tuning range of 200 MHz for 1 V increase in input voltage. The simulated power consumption of the oscillator was 1.2 nW. The design and simulation results of the ring oscillator with 180 nm technology will be presented and discussed. The presented oscillator, which is implemented in an ASIC, is applicable in advanced sensing systems, including environmental, chemical, and biological sensing.

9106-18, Session 5

Fabrication of D-type fiber optic sensors with a long interaction length and studying effects of critical parameters on sensor response

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Today Evanescent wave based fiber optic (F/O) platforms are in favor of the use for monitoring molecular interactions since they are practical, economic and easy to operate which make them ideal turnkey systems for clinical, pharmaceutical, environmental and security applications. Side polishing is one of techniques for reshaping the geometry of the waveguide to make the F/O sensor more sensitive to refractive index (RI) changes in the biolayer in Evanescent field. In this study D-type F/O sensors with a 25 mm-long interaction lengths are fabricated. In addition to that, effects of the critical parameters such as the polishing depth, the wavelength, and the temperature on the sensor response are determined for the RI in the range 1.33 - 1.47. The developing key of these F/O sensors is reaching high strength and penetration depth of Evanescent wave in varying RI of the surrounding biolayer. Development steps of D-type F/O sensors are; fabrication of silicon V channels, F/O cable preparation, adhesion, lapping and polishing, fusing the connectors, construction of the optical system, and RI measurements. Details of these steps are explained and the general characteristics of the D-type fiber optic sensor are presented. Results indicate that the sensor's responses in three different RI ranges can be improved by the polishing depth. A maximum resolution of 5x10-6 RIU for the D-type F/O sensors is demonstrated in the RI range from 1.44 and 1.46. The results will be used for development of plasmonic sensors with nanocomposite films consist of Al and nanostructured alumina layers.

9106-19, Session 5

On-chip plasmonic interferometer array for portable multiplexed biosensing system

Xie Zeng, Dengxin Ji, Nan Zhang, Haomin Song, Qiaoqiang Gan, Univ. at Buffalo (United States)

High-throughput microarray multiplexed biosensing is important for early detection of disease and drug screening, which currently rely on fluorescent-labeling techniques. However, since fluorescent labels often interfere with molecular binding interactions and lead to inaccurate measurement, there is a significant need for label-free biosensing technique. While prism-based surface plasmon resonance systems have become the archetype for label-free biomolecular and chemical sensing, reductions in size and instrumental complexity are desired for applications requiring low-cost, compact, portable sensors, including routine point-of-care clinical evaluation, real-time diagnosis of diseases in developing countries and fast genetic mapping for personalized care. Nanoplasmonic biosensors employing novel topographies are an attractive miniaturized platform to meet these requirements, which are mainly based on wavelength interrogation in most reports. However, high spatial density multiplexed measurements are difficult to achieve in these designs in that broadband wavelength analysis via spectrometer is required, which inevitably adds the size and cost of the entire sensing system. In this work, we develop a compact plasmonic interferometer biosensor platform constructed by nanogroove-slit pairs or nanogroove rings with a nanohole at their center. Surface plasmon modes generated at the nanogrooves will propagate to the nanoslit or hole to interfere with the free space light transmitted through the nanoslit/hole and enable the surface refractive index sensing. Importantly, this plasmonic interferometer can be fabricated in a large scale array and be directly imaged by miniaturized microscope system coupled with CCD/CMOS imagers to realize low cost and portable sensitive multiplexed biosensor systems.

9106-20, Session 6

Remote sensing modeling framework written in JavaScript language for interactive line-by-line transmission and lidar calculations using the HITRAN database

Denis V. Pliutau, Consultant (United States)

Optical remote sensing is extensively employed in a wide range of space, environmental, military and industrial fields. Very often there is a need in carrying out estimates of expected spectroscopic or lidar performance for instrument design, calibration and optimization purposes. Such optimizations are often based on line-by-line calculations using the HITRAN database. Current approaches for such line-by-line calculations rely on desktop programs or server-type computational resources. The advances in mobile devices have enabled the possibility of executing relatively complex and effective scientific codes using processing power of portable electronics facilitating their wider application both in the lab and field environment. We describe a line-by-line and lidar modeling framework developed to operate within a web-browser written in the JavaScript language based on the capabilities of the HTML5 specification. The newly implemented approach relies upon the processing power of a client device and enables easy user customizations of the modeling algorithms in addition to high portability. The employed alternative line-by-line calculation technique has never been implemented in the past to our knowledge and is very relevant to the ongoing transition of the HITRAN database to the SQL query type web-based format. Additionally, the approach enables direct usage of NASA Earth server data in simulations including vertical atmospheric profiles of pressure, temperature and molecular composition from the Modern Era Retrospective Analysis for Research and Applications (MERRA) and other datasets thus significantly enhancing location and time specific modeling capabilities. The approach may be combined with the use of geospatial visualization frameworks such as OpenLayers.

9106-21, Session 6

Optical characterization of nanoporous anodic alumina sensor substrate

Aschalew Kassu, Carlton W. Farley III, Anup Sharma, Alabama A&M Univ. (United States)

Nanoporous anodic aluminum oxide (AAO) has been investigated as an ideal and cost-effective chemical and biosensing platform. In this paper, we report the optical properties of periodic 100 micron thick nanoporous anodic alumina membranes with uniform and high density cylindrical pores penetrating the entire thickness of the substrate, ranging in size from 18 nm to 150 nm in diameter and pore periods from 44 nm to 243 nm. The geometry of the top and bottom surface of each membrane is studied using atomic force microscopy. The optical properties including transmittance, reflectance, and absorbance spectra on both sides of each substrate are studied and found to be symmetrical. It is observed that, as the pore size increases, the peak resonance intensity in transmittance and absorbance increases. The effects of the pore sizes on the optical properties of the bare nanoporous membranes and the benefit of using arrays of nanohole arrays with varying hole sizes and periodicity as a chemical sensing platform is also discussed. To characterize the optical sensing technique, transmittance and reflectance measurements of various concentrations of chemicals adsorbed on the bare nanoporous substrates are investigated. The results presented here show variation in transmittance and reflectance spectra with the concentration of the chemical used or the amount of the material adsorbed or the surface of the substrate.

9106-22, Session 6

Path Optimization For Oil Probe

Anthony O. Smith, Mark D. Rahmes, Mark Blue, Harris Corp. (United States); Adrian Peter, Florida Institute of Technology (United States)

We discuss a robust method for optimal oil probe path planning inspired by medical imaging. Horizontal wells require three-dimensional steering made possible by the rotary steerable capabilities of the system, which allows the hole to intersect multiple target shale gas zones. Horizontal “legs” can be over a mile long; the longer the exposure length, the more oil and natural gas is drained and the faster it can flow. More oil and natural gas can be produced with fewer wells and less surface disturbance. Horizontal drilling can help producers tap oil and natural gas deposits under surface areas where a vertical well cannot be drilled, such as under developed or environmentally sensitive areas. Drilling creates well paths with have multiple twists and turns to try to hit multiple accumulations from a single well location. Our algorithm can be used to augment current state of the art methods. Our goal is to obtain a 3D path with nodes describing the optimal route to the destination. This algorithm works with BIG data and saves cost in planning for probe insertion. Our solution may be able to help increase the energy extracted vs. input energy.

9106-28, Session 6

Cloud droplet number concentration observed over ocean from CALIOP/CALIPSO and MODIS/AQUA

Shan Zeng, Oak Ridge Associated Universities (United States) and NASA Langley Research Ctr. (United States); Charles R. Trepte, Yong-Xiang Hu, David M. Winker, Lusheng Liang, NASA Langley Research Ctr. (United States)

Cloud droplet number concentration (CDNC) is an important microphysical property of liquid clouds that impacts radiative forcing, precipitation and interacts with aerosols. Remote sensing of this parameter at global scales from satellites are still challenging, especially because retrieval algorithms developed for passive sensors (i.e. MODIS/Aqua) have to rely on the assumption of cloud adiabatic growth. The active sensor CALIOP/CALIPSO allows retrievals of CDNC from depolarization measurements at 532 nm. For that case, the retrieval does not rely on the adiabatic assumption but instead must use a priori information on effective radius (re), which can be obtained from other passive sensors. In this paper, re values obtained from MODIS/Aqua are used to constrain CDNC retrievals from CALIOP. Intercomparison of CDNC products retrieved from MODIS and CALIOP sensors is performed, and their differences are discussed. By analyzing the strengths and weaknesses of different retrieval techniques, this study aims to better understand global CDNC distribution, and eventually determine cloud structure and atmospheric conditions in which they develop. The improved understanding of CDNC would help for the future studies of global cloud-aerosol-precipitation interactions and parameterizations of clouds in the global climate models (GCMs).

9106-23, Session Posters-Tuesday

Optimal RS-measurements plan strengthening lab-measured information in coherent modes of nonlinear synergetic system

Galib G. Huseynov, Ivy Tech Community College (United States) and Northern Virginia Community College (United States)

The spatial and spectral contrasts’ transformation with survey conditions (altitude, atmosphere condition and illumination) illustrates smoothing with an altitude and optical distance in approach of thetransmission equation. Meanwhile there is an “oscillating” decrease tendency of a variation

coefficient observed with steady spikes to be described by some non-linear regression models based on synergy concepts. Usage of a spatial coherence parameters determined as a result of an interaction of eigen-functions of transmission equation with fluctuating component allows to develop the calibration metrics with informative ranges of data processing selection

9106-24, Session Posters-Tuesday

Humidity sensor based on zinc (II) oxide-titanium (II) oxide nanocomposite

Karunesh Tiwari, BBDNITM Lucknow (India); N. K. Pandey II, Lucknow Univ. (India)

A new compact, durable, yet highly sensitive and reliable ceramic humidity sensor based on the semiconducting metal oxide ZnO-TiO2 has been prepared by using solid-state reaction method. The nanostructure and humidity sensitivity of Titanium Oxide (TiO2) doped ZnO has been investigated. Highly pure ZnO (99.99 Qualizens) and TiO2 (99.99 Qualizen) powder have been used. Samples have been prepared with compositions of 2wt% (Sample S-2), 5wt% (Sample S-5) of TiO2 with ZnO and mixed uniformly by using glaze mortar and pestle for half an hour. The resultant powder with 10 wt% of glass powder binder added has been pressed into pellets under pressure of 260 MPa for 3 hours. Pellets of these powders has been annealed in electric muffle furnace at temperature 200°C, 300°C, 400ºC, and 500ºC for three hours and cooled to room temperature. After sintering, these pellets have been exposed to humidity in a specially designed humidity chamber at room temperature. It has been observed that as relative humidity increases, resistance of the pellets decreases for entire range of humidity i.e. 10% to 90%. Rutile and hexagonal structures of ZnO-TiO2 and their nano meter grain sizes are responsible for formation of nanometer sized pores, which ultimately adsorbs water. The adsorption of water (physisorbrd water) on hydroxalated surface cause electron injection. The interaction of adsorbed oxygen with water molecules or possibly with chemisorbed water causes energy level of adsorbed oxygen ions to fluctuate, so that electrons can be more easily injected. It has been observed that the resistance of the pellet decreases as the relative humidity increases from 10%-90%.

9106-27, Session Posters-Tuesday

Analytical solution using computer algebra of a biosensor for detecting toxic substances in water

María Isabel Rua Taborda, Univ. EAFIT (Colombia)

In a relatively recent paper an electrochemical biosensor for water toxicity detection based on a bio-chip as a whole cell was proposed and numerically solved and analyzed. In such paper the kinetic processes in a miniaturized electrochemical biosensor system was described using the equations for specific enzymatic reaction and the diffusion equation. The numerical solution shown excellent agreement with the measured data but such numerical solution is not enough to design efficiently the corresponding bio-chip. For this reason an analytical solution is demanded. The object of the present work is to provide such analytical solution and then to give algebraic guides to design the bio-sensor. The analytical solution is obtained using computer algebra software, specifically Maple. The method of solution is the Laplace transform, with Bromwich integral and residue theorem. The final solution is given as a series of Bessel functions and the effective time for the bio-sensor is computed. It is claimed that the analytical solutions that were obtained will be very useful to predict further current variations in similar systems with different geometries, materials and biological components. Beside of this the analytical solution that we provide is very useful to investigate the relationship between different chamber parameters such as cell radius and height; and electrode radius.

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9107-1, Session 1

Confocal laser method (CLM) for multiparameter sensing and quantitative evaluation of optical properties of intraocular lens (IOL) implants

Bennett N. Walker, Robert H. James, Don Calogero, Ilko K. Ilev, U.S. Food and Drug Administration (United States)

Intraocular lens (IOL) implantation is the most common surgical procedure in the United States, averaging over 3 million surgeries per year. To keep up with the rapidly growing industry and evaluate the efficacy and safety of IOL optical properties, a precise, accurate, and repeatable technique is required. Recently, we have introduced a novel confocal laser method (CLM) for multiparameter sensing and effective evaluation of fundamental IOL optical properties such as dioptric power, refractive index, thickness, and geometrical parameters. The CLM principle is based on a simple fiber-optic confocal laser design that integrates advanced properties of high resolution confocal microscopy and fiber-optic sensing. This IOL testing approach enabled improved accuracy (<1 μm), improved repeatability (<0.01 D), and a broadened range of accessible dioptric powers (0 to ±36.0 D). Here, we discuss the continued development of the optical CLM platform through automation and introduced standard environmental control. The automation of the CLM platform improves the precision, repeatability, and simplicity for measuring dioptric powers of new IOL designs. In addition, the IOL can be placed in an environmentally controlled chamber where temperature, surrounding medium and optical properties can be monitored and manipulated. Preliminary studies have measured the impact of changes in experimental wavelength of light and laser beam profiles on spherical and cylinder powers for various IOL types (e.g. toric, monofocal, and multifocal). These studies, and others, can significantly improve the proficiency of evaluating the safety and efficacy of IOL optical properties and ultimately the health of millions of Americans every year.

9107-2, Session 1

Novel fiber optic Fourier transform infrared (FO-FTIR) spectroscopy platforms for label-free remote sensing of biochemical contamination

Moinuddin Hassan, Ilko K. Ilev, U.S. Food and Drug Administration (United States)

Medical device contamination has become a critical and prevalent public health issue as devices are being extensively used in clinical practices for diagnostics, therapeutics, and medical implants. In order to prevent transmission of infection to patients and healthcare personnel caused by medical device contamination, the development and implementation of novel test methods for quantitative, accurate, easy-to-use, and real-time detection of contaminations is required. Conventional clinical methods based on swab/wipe sampling are not sensitive enough and can be time consuming. Here, we have developed an alternative fiber-optic Fourier transform infrared (FO-FTIR) spectroscopy based sensing platforms (reflectance, transmission and grazing incident angle (GIA)) for label-free, remote, and rapid detection of medical device surface contaminations. We demonstrated the sensitivity of the FO-FTIR reflection and GIA measurement modality for non-contact, label-free identification of endotoxin as well as protein samples such as bovine serum albumin (BSA). In addition, we also investigated sensitivity of the FO-FTIR as compare to colony forming units of different types of bacteria such as Escherichia coli, Staphylococcus aureus, and Pseudomonas. The novel sensing platforms integrated with the signal recognition statistical approach can provide a powerful optical tool for non-contact, real-time, in-situ detection and identification of biochemical contaminants of medical device surface within the FDA and CDC recognized threshold limits.

9107-3, Session 1

Modeling of irradiation by a collimated line source in multilayer anisotropic media for a biomedical optical probe

Dagmar A. Wismeijer, Lieke G. E. Cox, Par Dunias, TNO Science and Industry (Netherlands)

The development and applicability of a forward-looking optical probe in the medical field, e.g. to detect tumors in breast tissue, can be greatly enhanced by the use of a predictive mathematical light-tissue interaction model. To this end, we developed an analytical model that predicts irradiation of an anisotropic light source inside layered anisotropic scattering media of finite thicknesses, as well as in semi-infinite media.

Most models to date either rely on the diffusion approximation-which is not valid close to the source, or pertain to a (semi-)infinite turbid medium-which is not always close to reality. The model we present here overcomes both drawbacks for practical application, by taking into account the anisotropy of the media and the source.

Assuming an anisotropic line source inside an infinite anisotropic scattering medium, we solved for the resulting radiative transport equation (RTE) in the spatial frequency domain (SFD) and back-transformed our solution into the spatial domain using the Hankel-transformation. Based on this, we solved the semi-infinite, finite-sized slab and dual-layer media cases by applying the corresponding boundary conditions (extrapolated BC) in the SFD and solved the resulting RTE.

The spatial transmission profiles predicted by our model were in close agreement with the profiles predicted by Monte Carlo simulations for a great variety of optical parameters and layer configurations . In addition, the semi-infinite model was verified by measuring with a hyper-spectral single point optical probe in a semi-infinite medium, and in a next stage, the model will be verified for a dual-layered medium.

9107-4, Session 1

High resolution optical fibre pressure and temperature sensor for medical usage in cardiovascular and in-vivo urodynamic measurements

Sven Poeggel, Daniele Tosi, Univ. of Limerick (Ireland); Simone Sannino, Laura Lupoli, Univ. degli Studi di Napoli Federico II (Italy); Dinesh Babu Duraibabu, Univ. of Limerick (Ireland); Fernando Fusco, Juliet Ippolito, Vincenzo Mirone, Univ. degli Studi di Napoli Federico II (Italy); Gabriel Leen, Elfed Lewis, Univ. of Limerick (Ireland)

Medical sensors, in general, are required to have a high accuracy and to provide a high measurement resolution with a small drift. Measurements need to be repeatable, i.e. the sensor has to be stable over long time intervals. Furthermore the sensors need to be very compact, especially when used in constricted areas e.g. blood vessels or the lung.

Since optical fibres are small in size (e.g.: diameter of 125-200um), they are potentially suitable for medical usage. Compared to other state-of-the-art in-situ sensing technologies, optical fibre sensors have useful inherent advantages such as resistance to chemical degradation, immunity to electromagnetic fields (as experienced in MRI or CT scanners) and furthermore, all-glass fibre optic sensors are biocompatible.

The Optical Fibre Pressure and Temperature Sensor (OFPTS) present here is able to measure pressure and temperature simultaneously. The OFPTS combines an Extrinsic Fabry Perot Interferometer (EFPI) to measure pressure, with an internal Fibre Bragg Grating (FBG) to measure

temperature.

The OFPTS has been tested in a simulated cardiovascular environment and showed a resolution of 0.1mmHg with an online frame-rate of 100Hz. The sensor was also tested in the Polymer Core Center in the Cleveland Clinic and demonstrated a pressure drift of less than 1mmHg over a 1 hour period. Furthermore, the sensor has also been tested in-vivo, in a urodynamics application where 7 patients participated at the Urologic Clinic in Federico II University of Naples, in Italy. The Analyses show a good correlation between the used reference sensor (Pico-2000) and the OFPTS, present here.

9107-5, Session 1

Multifunction medical endoscope system with optical fiber temperature sensor

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Thermal therapy (e.g. RF treatment, RF ablation, microwave cutting etc.) is one of the effective operations for tumor treating and curing. Since tumor tissues are more susceptible to heat than normal tissues, in thermal therapy operations, temperature is a crucial parameter. As the temperature is too low, the tumor tissues cannot be killed; otherwise, the temperature is too high, the operation may damage the normal tissues around tumors. During thermal a therapy operation, the heating power is normally supplied by high-frequency EM field, so traditional temperature sensors, such as thermal couples, thermistors, cannot work stably due to EM interference. We present a multi-function endoscope optical fiber temperature sensor system. With this sensor setup based on principle of fluorescence life time, the temperature on operation point is detected in real time. Furthermore, a build-in endoscope centered in the fiber sensor, so the operation field can be viewed or imaged directly in the operation. This design can navigate the operation, particularly for in vivo operations. In the sensor system, the temperature sensor measurement range is 30°C-150°C, the resolution achieved 0.3°C, the imaging fiber buddle contains more than 50k fibers. As the sensor probe is very thin (less than 2mm in diameter), it can be assembled in the RF operation knife. With the presented sensor system in clinic operation physicians can check the temperature in the operation point and view the operation point at the same time.

9107-6, Session 2

Towards a portable ultrahigh resolution SERS imaging system

Eric R. Languirand, John Kiser, Brian Cullum, Univ. of Maryland, Baltimore County (United States)

Ultra-high resolution chemical imaging using Raman spectroscopy can aid in the differentiation and identification of trace analytes for many applications, including, but not limited to forensics, environmental, biological and biomedical sciences. Unfortunately, spontaneous Raman spectroscopy is an intrinsically weak phenomenon making trace detection inherently difficult. To circumvent this and provide the sensitivity necessary for sub-diffraction limited chemical imaging, we employ a specially designed surface enhanced Raman spectroscopic (SERS) nanoprobe. Unlike tip enhanced Raman spectroscopy (TERS), where a small tapered tip is raster scanned over a sample surface for ultra-high resolution image acquisition, our nanoprobes are fabricated from fiber optic imaging bundles that allow for an entire image to be acquired in a single collection.

The SERS nanoprobes, which are central to this system, are fabricated using coherent fiber-optic imaging bundles consisting of 30,000 fiber elements. These probes are tapered via a micropipette puller to have individual fiber element tip diameters of 50 nm and still retain total internal transmission. Using a rapid 2-step dithering process, 20 µm diameter images can be obtained with 33-36 nm spatial resolution. The rapid dithering process coupled with the simultaneous multilocation collection allows for ultra-high resolution, dynamic imaging to be achieved. This talk will describe the development of a portable system for field applications.

9107-7, Session 2

Noninvasive label-free and real-time sensing of hydrogen peroxide in human brain cancer cells through Raman spectroscopy

Darrell B. Tata, U.S. Food and Drug Administration (United States)

Noninvasive optical diagnostics and therapeutics modalities provide non-contact, high-resolution, fast and painless tools for diagnostic sensing and treatment of a variety of diseases. However, despite recent intensive research efforts, there is a fundamental lack of understanding of the working mechanisms of light-tissue interactions involved with various optical therapeutic techniques and devices. These mechanisms need to be understood at the cellular/intracellular level in order to optimize effectiveness and ensure safety of photodynamic treatments which results in pain relief, and light-assisted cellular and tissue repair. One of the recently investigated hypotheses of light-tissue interaction mechanism is that hydrogen peroxide (H2O2) as one of the laser-induced reactive oxygen species (ROS) is likely to play a dominant role for light induced modulations of biological responses. In an initial proof-of-concept study, we have demonstrated recently the first direct noninvasive, real time monitoring and label-free sensing of H2O2 in human cancer cells using an innovative sensing approach based on Raman spectroscopy. In the current study, we present further quantitative experiments on optimizing critical laser parameters (such as spectral wavelength; continuous-wave vs. pulse; optical power/energy; laser beam parameters and irradiation dose) for laser induced H2O2 in-vitro.

9107-8, Session 2

Characterization of ultrathin oxide based multilayer SERS nanoprobes for intracellular sensing

Pietro Strobbia, Adam Mayer, Charles Klutse, Brian Cullum, Univ. of Maryland, Baltimore County (United States)

The intracellular study of chemical signaling play a key role in the development of medicine as well as fundamental understanding of biological phenomena. Photonic nanosensors (e.g. PEBBLES, quantum dots-based sensors, etc.) have begun to allow the study of these previously inaccessible environments. Unfortunately, many current techniques suffer from biocompatibility issues, limited ability to monitor multiple species simultaneously and/or complicated fabrication chemistries. Recently SERS immuno-nanoprobes have demonstrated the capability to overcome many of these limitations. Such intracellular SERS nanosensors require an optimized substrate geometry to achieve the sensitivity necessary to detect the trace analyte concentrations present. To address this, we have developed a novel multilayered SERS substrate nanoarchitecture that is capable of enhancing SERS signals by over two orders of magnitude relative to comparable single layer substrates. These structures are fabricated using different deposition techniques (PVD, ALD, etc) in which multiple films of Ag (between 10-125 nm thick) are alternately deposited with ultrathin dielectric layers (tens of Å). This geometry allows surface plasmons from different metal layers to be generated. The resulting multilayer enhancement increases the sensitivity while also improving the robustness of the nanoprobes. In this paper, we investigate the sensitivity of SERS immuno-nanoprobes fabricated using this multilayered geometry and discuss the effect of the dielectric spacer (Ag2O, TiO2, Ta2O5) work functions and conductive band offsets on the multilayer enhancement. In addition, further enhancement associated with optical trapping of the nanoprobes during analysis will also be discussed as well as the development of gold multilayer nanoprobes.

9107-9, Session 2

Detection of illicit drugs in impaired driver saliva using a field-usable SERS analyzer

Stuart R. Farquharson, Chetan S. Shende, Hermes Huang, Real-Time Analyzers, Inc. (United States)

One of the greatest dangers of drug use is in combination with driving. More than 11% of drivers in a 2007 National Highway Traffic Safety Administration's (NHTSA) roadside survey tested positive for illicit drugs, while 18% of drivers killed in accidents tested positive for illicit, prescription or over-the-counter drugs according to a 2009 NHTSA survey. Consequently, there is a need for a rapid, noninvasive, roadside drug testing device, similar to the breathalyzers used by law enforcement officials to estimate blood alcohol levels of impaired drivers. In an effort to satisfy this need we developed a portable analyzer that automatically extracts the drugs from saliva and generates surface-enhanced Raman spectra (SERS). This presentation will describe the automated sampling system, the development of a 150 drug SERS library, and the analysis of 8 priority drugs in 1 mL saliva samples in ~ 10 minutes at 10-50 ng/mL (part-per-billion) using a portable Raman analyzer.

9107-10, Session 2

Rapid detection of Pseudomonas aeruginosa biomarkers in biological fluids using surface-enhanced Raman scattering

Xiaomeng Wu, Jing Chen, The Univ. of Georgia (United States); Susu M. Zughaier, Emory Univ. (United States); Yiping Zhao, The Univ. of Georgia (United States)

Pseudomonas aeruginosa (PA) is an opportunistic pathogen that causes major infection not only in Cystic Fibrosis (CF) patients but also in chronic obstructive pulmonary disease and in critically ill patients in intensive care units, inducing ventilator associated infections. Successful antibiotic treatment of the infection relies on accurate and rapid identification of the infectious agents, but conventional detection methods usually take more than 3 days to get accurate results. We have developed a rapid diagnostic technique based on surface-enhanced Raman scattering (SERS) to directly identify PA from biological fluids. PA strains PAO1 and PA14 are cultured in lysogeny broth, and the SERS spectra of such broth show the signature Raman peaks from Pyocyanin (PYO) and pyoverdine (PVD), two major biomarkers that PA secretes during its growth. This provides the evidence that the presence of these biomarkers can be used to indicate PA infection. A total of 22 clinical exhaled breath condensates (EBC) samples were obtained from subjects with CF disease and from non-CF healthy donors. SERS spectra of these EBC samples were obtained and further analyzed by using both principle component analysis (PCA) and partial least square-discriminant analysis (PLS-DA). PLS-DA can discriminate the samples with PA infection and the ones without PA infection at 99.3% sensitivity and 99.6% specificity. In addition, this technique can also discriminate samples form subject with CF disease and healthy donor with 97.5% sensitivity and 100%. These results demonstrate the potential of using SERS of EBC samples as a rapid diagnostic tool to detect PA infection.

9107-11, Session 3

Determining hearing loss due to perforation in the tympanic membrane using image processing techniques

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The tympanic membrane (ear drum) is a thin tissue film that is stretched between the outer and middle ear. Sound waves travel from outside the ear, and strike the tympanic membrane resulting in its vibration. These vibrations amplify the sound waves and transmit them to the ossicles (auditory bones). The magnitude of amplification is directly proportional to vibrating area of the tympanic membrane. Hence a perforation in this membrane would result in hearing loss.

Pure-tone audiometry is the traditional procedure used to detect the amount of hearing loss in a patient. However, it is lengthy and less efficient, as it largely depends on the response of the patient to sound intensity and frequency of pure-tones.

We present a relatively more efficient approach to determine hearing loss due to perforated tympanic membrane using image processing techniques. We describe an algorithm that uses unsharp masking to sharpen images of the perforations as well as the tympanic membrane. Then, it converts the image into a binary image using thresholding. A median filter is applied to get rid of the noise component in the image. The ratio of the area of perforation and total area of tympanic membrane will define the percentage of hearing loss. Our approach will eliminate the error introduced due to patient dependency as in the traditional method.

9107-12, Session 3

Quantitative analysis of low contrast detectability in optical coherence tomography using spin-coated phantoms

Nicholas J. Woolsey, Hsing-Wen Wang, Univ. of Maryland, College Park (United States) and U.S. Food and Drug Administration (United States); Anant Agrawal, U.S. Food and Drug Administration (United States); Jianting Wang, Univ. of Maryland, College Park (United States) and U.S. Food and Drug Administration (United States); Chia-Pin Liang, Yu Chen, Univ. of Maryland, College Park (United States); T. Joshua Pfefer, U.S. Food and Drug Administration (United States)

Optical Coherence Tomography (OCT) is a high resolution imaging technology that is rapidly being adopted as the standard of care for medical applications such as ocular and intravascular imaging. However, clinical translation has been hampered by the lack of standardized test methods for performance evaluation as well as consensus standards analogous to those that have been developed for established medical imaging modalities (e.g., ultrasound). In this study, we address low contrast detectability, specifically, the ability of systems to differentiate between regions exhibiting small differences in scattering coefficient. Based on standard test methods for other medical imaging modalities, we have developed layered phantoms with well-characterized scattering properties in a biologically relevant range. The phantoms consisted of spin-coated layers of polydimethylsiloxane (PDMS) doped with varying concentrations of barium sulfate microparticles. Two spectral domain OCT systems – a Fourier domain device at 830 nm and a swept-source device at 1310 nm – were then used to image the phantoms. The low contrast detectability of each system was evaluated from the pixel intensity difference between layers. Confounding factors such as the inherent attenuation of the phantoms, signal intensity decay due to focusing and system roll-off were also encountered and addressed. Significant differences between systems were noted. The minimum differences in scattering coefficient that the Fourier domain and swept source systems could differentiate was 1.83 and 0.40 mm-1 respectively. Overall, this approach to evaluating low contrast detectability represents a key step towards the development of standard test methods to facilitate clinical translation of novel OCT systems.

9107-13, Session 3

Contrast-detail and penetration depth phantoms for hyperspectral reflectance imaging

Jianting Wang, Univ. of Maryland, College Park (United States); James Coburn, U.S. Food and Drug Administration (United States); Chia-Pin Liang, Nicholas J. Woolsey, Univ. of Maryland, College Park (United States); Jessica C. Ramella-Roman, The Catholic Univ. of America (United States); Yu Chen, Univ. of Maryland, College Park (United States); T. Joshua Pfefer, U.S. Food and Drug Administration (United States)

Hyperspectral reflectance imaging (HRI) is an emerging technology with a variety of clinical applications such as tissue oximetry and cancer detection based on endogenous constituents or nanoparticles that enable molecular imaging. Currently, there is a lack of standardized test methods for objective, quantitative evaluation of HRI systems. Phantom-based contrast-detail analysis is a well-defined method that has been applied to many other medical imaging modalities such as mammography and ultrasound imaging. Penetration depth is also typically determined for these modalities using phantom-based approaches. Here we fabricated and implemented two types of tissue-simulating phantoms for HRI: (1) those for contrast-detail analysis containing micro-fluidic channels of a range of sizes at the same depth and (2) those for penetration depth analysis containing channels of the same diameter at a range of depths. Phantoms were constructed using two novel approaches. Three-dimensional (3D) printing was used to generate phantoms with rectangular channels having lateral dimensions of 0.4 to 2 mm and a depth range of 0.3 to 2 mm. Molds fabricated through photolithography were used to produce scatterer-doped polydimethylsiloxane (PDMS) phantoms containing cylindrical channels of 0.15 to 0.5 mm diameter and 0.2 to 2 mm depth. Detectability of channels in both phantoms were measured using various concentrations of gold nanorods and gold nanoshells. Both phantoms demonstrated feasibility for performing contrast-detail and penetration depth analyses. Although 3D printing provides a faster, simpler and more flexible way to print phantoms than photolithography, the latter technique produces smaller channels with more ideal cylindrical geometry and matrix regions with readily tunable optical properties.

9107-14, Session 3

Effect of surface texture to the biofilm attachment on medical device surfaces studied by hyperspectral imaging

Hanh N. D. Le, Victoria M. Hitchins, Ilko K. Ilev, Do-Hyun Kim, U.S. Food and Drug Administration (United States)

Biofilms cause serious risk of infection when present on medical device surfaces, especially for implanted devices. Therefore, it is important to monitor and prevent biofilm formation on these devices. Due to its wideband and rapid detection potential, hyperspectral imaging was used in this study to differentiate biofilm spectra on various device material surfaces. Surfaces of interest included coupons of different stainless steel textures: mirror-polished, un-polished and two intermediate degrees of brushed surfaces. Following the growth of Pseudomonas aeruginosa bacteria on coupons after 24, 48 and 72 hours at 37 oC, the coupons containing biofilm were tilted at 10, 45 and 90 degree for 30 seconds to induce shear stress. Adherence was tested using hyperspectral imaging. Sample examination on several medical device materials and textures not only revealed the amount of adhesion of biofilms, but also the influence of biofilm production on different metallic and polymeric materials. Further discussion of biofilm adhesion on other materials such as polytetrafluoethylene, titanium, polycarbonate and glass will be presented.

9107-15, Session 3

Use of high dynamic range technique for hyperspectral imaging for surgical applications

Maritoni Litorja, National Institute of Standards and Technology (United States)

Multi or hyperspectral imaging has been used to measure reflectance of various tissues in the surgical cavity. The objective of using hyperspectral imaging is to bring spectroscopic technique for feature identification as well as anomaly detection. The reflected light from surgical images can vary in magnitude far greater than the dynamic range of the imager. This poses a problem in spectroscopic analysis due to glare spots and dark absorbent areas. High dynamic range technique has been routinely used in photography to extend a digital camera's range and capture the range of illumination values in the original environment. In this paper we explore the use of high dynamic range technique as a method to extend the dynamic range of a hyperspectral imager.

9107-16, Session 4

Rapid biofluid analysis using paper-based devices and mass spectrometry

Justin M. Wiseman, Prosolia, Inc. (United States); Nicholas E. Manicke, Purdue Univ. (United States)

The rapid pace of innovation in mass spectrometry over the last decade has resulted in higher performing instruments and unique sample introduction methods that simplify analysis and enable in situ examination of a diverse set of sample types. PaperSpray is a recent development that allows for quantitative analysis drugs in biological fluids (i.e. blood, plasma, urine) without sample preparation prior to mass analysis. A few microliters of fluid is deposited onto a paper-based substrate where the analytes are dissolved in an elution solvent and are ionized via electrospray for introduction into the mass spectrometer. This technique has been applied to the quantitation of immunosuppressants, antineoplastics, and drugs of abuse in whole blood and urine, without sample preparation. Here we present this novel technique with emphasis on its performance and cross-validation with conventional methods.

9107-17, Session 4

Transient flow with memory in a nanocapillar

Mateo Pineda Osorio, Univ. EAFIT (Colombia)

A model of transient flow with memory in a nanocapillar is formulated and anallitically solved. Nanofluidics behavior is described by Navier-Stokes Equation when viscosity is a radially modulated parameter and by a border condition corresponding with hysteretic sliding on the nanocapillar wall. Solution is obtained using the Laplace Transform, and Bromwich Integral and the Residue Theorem for the Inverse Laplace Transform; with the final result being expressed as an infinite series of Bessel Functions. The analytic solution for the case with material memory is compared with the analytic solution for the case with no material memory and with constant viscosity. A formula for the development of nanodynamic impedance is deduced. Analytic results are shown to be relevant in the design of nanofluidics devices with applications in general nanotechnologies and pharmaceutical engineering in particular. Future lines of research are also suggested.

9107-18, Session 4

Characteristic impedance of a micro-capillar with two immiscible microfluids

Daniela Jaramillo Raquejo, Univ. EAFIT (Colombia)

Consider the case of a microcapillary of radius R whit two microfluidic immiscible. The micro-capillary region 0 < r < R [1] is occupied by the microfluidic less dense and less viscous; while the microcapillary region R [1] <0 < R is occupied by the microfluidic more dense and more viscous. Determine the characteristic impedance of the microcapillary in this case when both microfluidics are driven by the same pressure gradient as the boundary condition at the wall of the microcapillary is of the non-Newtonian slip.The Navier Stokes equation is solved for both microfluidic methods using the Laplace transform. The velocity profiles are expressed in terms of Bessel functions. Similarly, the characteristic impedance of the microcapillary is expressed by a complex formula Bessel functions. Obtained The analytical results are important for designing engineering microdevices with applications in pharmaceutical, food engineering, nanotechnology and biotechnology in General in particular. For future research it is interesting to consider the case of boundary conditions with memory effects.

9107-19, Session 4

Microfluidic preparation of radiopharmaceuticals for use in imaging studies

Thomas L. Collier, Advion, Inc. (United States)

Microfluidics have revolutionized the field of radiopharmaceuticals in allowing for the rapid optimization of chemical processes and increased productivity in the preparation of radiotracers used in the development of imaging agents for clinicial research and the study of biological processes. This presentation will include an overview of microfluidics advances over the past 5 years in the field of radiochemistry and will including other areas such as electrochemistry, separation methodolgies, photochemistry, gas trapping and high level radiotracer production. A number of advances will be included as they relate more to the needs of microfluidics in the field of radiotracer production for pre-clinicial and clinical drug development. These include the rapid preparative purification of materials using a pre-column and analytical column for high purity purification of materials. The direct trapping of radioactive gases into a solution for use in radiotracer production. There have been thoughts that multicurie levels were not possible in the microfluidic environment due to the potential for autoradiolysis. Radioactive concentrations of >370GBq/ml have been used on a microfluidic platform and have been used to prepare clinically useful amounts of radiotracers.

9107-20, Session 4

Generalized electroosmosis transport with a spatially modulated electric permittivity inside a cylindrical micro channel

Juan José Cadavid Muñoz, Univ. EAFIT (Colombia)

After analyzing the behavior of a fluid using an electroosmosis transport system, it was shown that the analysis of a constant electric permittivity could also be extended to a medium in which its electrical properties are space dependent.

Using the hydrodynamic analysis with the Navier-Stookes equation in a high symmetric stationary environment and by solving the Maxwell's equations for only electrical charge sources within a micro channel, in the case where the electrical properties of the fluid changed along the space. In this case, it was considered a linear and a quadratic relation of the spatially modulated electric permittivity. For the first case, the solution was obtained in the terms of the Heun functions and in the second case the solution was given in terms of the Legendre polynomials. For both cases, the analytical solutions were obtained using the Maple software.

After evaluating these results with the solutions obtained with the Bessel's special functions, it provided a close approximation of the behavior of the fluid under the electroosmosis effect with constant permittivity.

With the development of this comparison between these solutions for the non constant fluid's electric characteristics, the analysis could be brought into the field of non-single-phase fluids, so it might allow a further analysis of the electroosmosis within a more realistic fluid, in which properties changes among the space inside a micro channel.

9107-21, Session 4

Nanofluidic structures for coupled sensing and remediation of toxins

Paul W. Bohn, Nicholas M. Contento, Kayla Shaw, Univ. of Notre Dame (United States)

One foundational motivation for chemical sensing is that knowledge of the presence and level of a chemical agent informs decisions about treatment of the agent, for example by sequestration, separation, or chemical conversion to a less harmful substance. Commonly the sensing and treatment steps are separate. However, the disjoint detection/treatment approach is neither optimal, nor required. Thus, we are investigating how nanostructured architectures can be constructed so that molecular transport (analyte/reagent delivery), chemical sensing (optical or electrochemical) and subsequent treatment can all be coupled in the same physical space during the same translocation event. Chemical sensors that are uniquely well-poised for integration into 3-D micro-/nanofluidic architectures include those based on plasmonics and impedance. Following detection, treatment can be substantially enhanced if mass transport limitations can be overcome. In this context, in situ generation of reactive species within confined geometries, such as nanopores or nanochannels is of significant interest, because of its potential utility in overcoming mass transport limitations in chemical reactivity. Solvent electrolysis in electrochemically coupled nanochannels supporting electrokinetic flow for the generation of reactive species, can produce arbitrarily tunable quantities of reagents, such as H2, in situ in close proximity to the site of a hydrogenation catalyst, for example. Semi-quantitative estimates of the local H2 concentration are obtained by comparing the spatiotemporal fluorescence behavior and current measurements with finite element simulations accounting for electrolysis and subsequent convection and diffusion within the confined geometry. H2 saturation can easily be achieved at modest overpotentials.

9107-22, Session 5

Thermal effects in microfluidics with thermal conductivity spatially modulated

Agustín Vargas Toro, Univ. EAFIT (Colombia)

A heat transfer model on a microfluidic is resolved analytically. The model describes a fluid at rest between two parallel plates where each plate is maintained at a differentially specified temperature and the thermic conductivity of the microfluidic is spatially modulated. The heat transfer model in such micro-hydrostatic configuration is analytically resolved using the technique of the Laplace transform applying the Bromwich Integral and the Residue theorem. The temperature outline in the microfluidic is presented as an infinite series of Bessel functions. It is shown that the result for the thermal conductivity spatially modulated has as a particular case the solution when the thermal conductivity is spatially constant. All computations were performed using the computer algebra software Maple. It is claimed that the analytical obtained results are important for the design of nanoscale devices with applications in biotechnology. Furthermore, it is suggested some future research lines such as the study of the heat transfer model in a microfluidic resting between coaxial cylinders with radially modulated thermal conductivity in order to achieve future developments in this area.

9107-23, Session 5

Using Lambert W function and error function to model phase change on microfluids

Anderson Bermudez García, Univ. EAFIT (Colombia)

Solidification and melting modeling on microfluidic are solved using Lambert W's function and error's functions. Models are formulated using the heat's diffusion equation. The generic posed case is the melting of a slab with time dependent surface temperature, having a micro or nano-fluidic liquid phase. At the beginning the solid slab is at melting temperature. A slab's face is put and maintained at temperature greater than the melting limit and varying in time. Lambert W function and error function are applied via Maple to obtain the analytic solution Evolution of the front of microfluidic-solid interface is analytically computed and slab's corresponding melting time is determined. It is expected to have analytical results to be useful for food engineering, cooking engineering, pharmaceutical engineering, nano-engineering and bio-medical engineering.

9107-24, Session 5

Lab-on-a-chip PCR: real time PCR in miniaturized format for HLA diagnostics

Claudia Gärtner, Holger Becker, Nadine Hlawatsch, Richard Klemm, René Sewart, Christian Moche, microfluidic ChipShop GmbH (Germany); Rainer Frank, Andreas Willems, inno-train Diagnostik GmbH (Germany)

In case of transplantation or the identification of special metabolic diseases like coeliac disease, HLA typing has to be done. In particular in the event of the decision of compatibility of donor and receptor for transplantation, fast results combined with easy to handle devices are necessary. Usually a limited amount or even a single sample needs to be analyzed immediately.

Provided this prerequisite a lab-on-a-chip device was realized, enabling a fast HLA typing through miniaturized real-time PCR. Starting the analysis with whole blood, two main process steps are involved, namely the extraction of DNA from blood, followed by the amplification of the target DNA by real time PCR combining amplification with direct measuring leading to a semi-quantitative result.

For the implementation of this complete process on chip, a sample preparation and a real time module were used. Sample preparation was carried out by using magnetic beads that are stored together with lysis reagents in dry format directly on chip. After clean up through applying a special buffer regime the DNA was transferred in the PCR module for amplification and detection through real time PCR. Coping with a massively increased surface-to-volume ratio leading to a higher amount of unspecific binding on the chip surface, special additives need to be integrated to compensate for this effect.

Finally the overall procedure showed a sensitivity comparable to standard real time PCR but cutting the complete analysis time to significantly less than one hour.

The presented work demonstrates that the combination of lab-on-a-chip PCR with direct read out through optical means in a real time fashion is an extremely promising tool for molecular diagnostics.

9107-25, Session 5

Fluorescence detection in a lab-on-a-chip system using ultrafast nucleic acid amplification methods

Rainer Gransee, Ralf Himmelreich, Julian Hoeth, Institut für Mikrotechnik Mainz GmbH (Germany)

Today, nucleic amplification plays a key role in modern molecular biology allowing fast and specific laboratory diagnostics testing. An ultrafast microfluidic module (allowing 30 polymeric chain reaction cycles (PCR) in 6 minutes) based on the oscillating fluid plug concept was previously developed [1]. This system allows the amplification of native genomic DNA from whole blood samples but still lacks some functionality compared to commercial bench top systems. This abstract presents the actual status of the renewed and advanced system, permitting the automated optical detection of not only the fluid plug position but also fluorescence detection. The system uses light emitting diodes (LED) for illumination and a low cost Charge-coupled Device (CCD) camera for optical detection. Image data processing allows the automated process control of the overall system components. Therefore, the system enables the performance of rapid and robust nucleic acid amplifications together with the integration of real time measurement technology. This allows the amplification and simultaneous quantification of the targeted deoxyribonucleic acid molecules (DNA). The possibility to integrate swift nucleic amplification and optical detection into complex sample-to-answer analysis platforms opens up new pathways towards fast and transportable point of care devices.

[1] Fast nucleic acid amplification for integration in point-of-care applications, Electrophoresis 2012, 33, 3222–3228

9107-26, Session 5

Microsystem integrated immunosensor for the detection of the bioterrorist agent Francisella tularensis

Samuel Dulay, Univ. Rovira i Virgili (Spain); Sandra Julich, Herbert Tomasso, Friedrich-Loeffler-Institut (Germany); Sebastian Schattschneider, Claudia Gärtner, microfluidic ChipShop GmbH (Germany); Rainer Gransee, Institut für Mikrotechnik Mainz GmbH (Germany); Ciara K. O'Sullivan, Univ. Rovira i Virgili (Spain)

A microsystem integrated electrochemical immunosensor was developed for the detection of both the lipopolysaacharide (LPS) of Francisella tularensis, as well as for whole cells (LVS). Antibody-horse radish peroxide and Fab-horse radish conjugates conjugates were prepared in-house. Various antibody combinations as capture and reporter antibodies were compared using ELISA and the optimum pair in terms of sensitivity and detection limit were transferred to an electrochemical set-up, housed within microfldluic packaging. Antibody fragments (Fab) were generated and used both as capture and reporter probes and compared to the use of whole antibodies. Assay parameters (incubation time, temperature, pre-mixing of sample with labelled antibody) were optimised and low detection limits of ca. 100 bacterial cells/mL were achieved. In an alternate immunosensor set-up, detection of anti-Francisella tularensis antibodies was achieved. In this case the use of LVS vs LPS was compared as coating agent in terms of binding capacity. Protein A-HRP was used as a reporter molecule, and incubation times and temperatures were optimised. The developed immunosensor was applied to the detection of real serum samples obtained from foxes and an excellent correlation with ELISA results was obtained. Functionalised electrodes are being subjected to real-time and Accelerated Arrhenius Thermal stability studies.

9107-27, Session 5

Lab-on-a-chip modules for detection of highly pathogenic bacteria: from sample preparation to detection

Sandra Julich, Friedrich-Loeffler-Institut (Germany); Rok Kopinc, Institute of Microbial Sciences and Technologies (Slovenia); Nadine Hlawatsch, Richard Klemm, Christian Moche, microfluidic ChipShop GmbH (Germany); Ales Lapanje, Institute of Microbial Sciences and Technologies (Slovenia); Claudia Gärtner, microfluidic ChipShop GmbH (Germany); Herbert Tomaso, Friedrich-Loeffler-Institut (Germany)

Lab-on-a-chip systems are promising tools for the detection and identification of microbial pathogens in human and veterinary medicine. The major advantages are small sample volume and a compact design that allows bed-side or pen-side diagnostics. Several fluidic modules have been developed to transform analytical procedures into miniaturized scale including sampling, sample preparation, target enrichment, and detection procedures.

We present evaluation data for single modules that will be integrated in a chip system for the detection of highly infectious, zoonotic pathogens that are considered also as biological agents.

A microfluidic chip system for purification of nucleic acids was established that combines cell lysis and target enrichment from several milliliters of liquid samples using magnetic beads. This assay was applied with air and swab samples and tested using samples spiked with bacterial suspensions and aerosols from the environment. Bacillus thuringiensis was used as simulant for Bacillus anthracis, which is closely related but non-pathogenic for humans.

An on-chip PCR module was tested for specific detection of pathogens. Two different technical approaches were investigated, a stationary PCR and a flow-through PCR. For six pathogens and an internal amplification control PCR assays could be transferred into chip scale using the same temperature/time profile.

We could demonstrate that the microfluidic chip modules are suitable for the respective purposes and are promising tools for the detection of bacterial pathogens. Future developments focus on the integration of these separate modules to an entire lab-on-a-chip system realizing the complete analytical process.

9107-28, Session 6

Multiplexed molecular detection of bioterrorist agents using microsystem integrated electrochemical genosensor array

Samuel Dulay, Univ. Rovira i Virgili (Spain); Sandra Julich, Herbert Tomasso, Friedrich-Loeffler-Institut (Germany); Sebastian Schattschneider, Claudia Gärtner, microfluidic ChipShop GmbH (Germany); Rainer Gransee, Institut für Mikrotechnik Mainz GmbH (Germany); Ciara K. O'Sullivan, Univ. Rovira i Virgili (Spain)

A multi-electrode array composed of gold working electrodes surrounded by gold counter and reference electrodes was designed and fabricated using photolithography. Surface chemistry was optimised to be ratio of 1:100 thiolated DNA probe:bipodal alkanethiol in order to obtain optimal spacing of the single stranded DNA probes to achieve maximum signal and minimum steric hindrance. Reporter probes linking a short DNA sequence to the enzyme horse radish peroxidase were prepared in house. Capture and reporter probes for the 8 targets (Coxiella burnetti, Bacillus anthracis, Bacteriophage lambda, Bacillus thuringiensis, Francisella tularensis holarctica, Burkholderia mallei, Brucella melitensis, Yersinia pestis) were designed to have minimal commanalities, and were evaluated both colorimetrically and electrochemically for cross reactivity. Functionalised electrode arrays were housed within a microfluidic set-up and linked to an automated pumping system. Hybridisation conditions (incubation duration and temperature) were optimised. The 8 different targets were amplified with PCR using biotinylated primers and single-stranded DNA was generated via streptavidin coated beads and thermal denaturation. The genosensor array was capable of subnanomolar detection limits and simultaneous detection of the 8 targets, with a total assay time of less than 10 minutes.

9107-29, Session 6

A pulsed sonoelectrodeposition technique for controlling nanomaterial structure in biosensing

Masashige Taguchi, Nate Garland, Neil Schwalb, Diana C. Vanegas-Gamboa, Stephanie L. Burrs, Eric S. McLamore, Univ. of Florida (United States)

Nanomaterial patterning can be achieved by self-assembly via specific molecular interactions in combination with various lithographic techniques (e.g. electron beam lithography, soft lithography, and dip-pen lithography). However, these techniques are expensive, time consuming, and require special equipment stored in a clean room. Standard electroplating techniques are capable of producing reliable thin films ≈ 0.5 to 5 μm thick. However, diffusion limitations and buildup of gaseous by-products limit the control of spatial patterning and therefore nanostructure performance. To resolve this problem, we have developed a custom pulsed sonication/electrodeposition system. During the sonication cycle, gaseous byproducts formed at the surface of the working electrode are removed, and sonolysis produces oxygen radicals near the surface of the electrode. Sonic energy removes unstable nanostructures which lead to a much more ordered and consistent deposition of nanostrcutures. A number of different cycling times were tested for the electrodeposition of amorphous nanoplatinum and gold nanoparticles on platinum/iridium electrodes. After deposition, electrode surface area was analyzed using cyclic voltammetry and DC potential amperometry. Nanoplatinum films formed using the pulsed sonoelectrodeposition (pSED) technique were more uniform than traditional plating alone, and electron transport was at least three times higher for structures created using pSED. In addition to the increased sensitivity, the nanomaterials demonstrated higher electroactive surface area and sensitivity toward hydrogen peroxide. The ability to control nanometal deposition with a user-friendly interface (simple graphic user interface) is a major advancement for improving control over nanostructure formation in the development of electrochemical sensors and biosensors.

9107-30, Session 6

Zinc oxide nanostructures for electrochemical cortisol biosensing

Phani Kiran Vabbina, Ajeet Kaushik, Nezih Pala, Shekhar Bhansali, Florida International Univ. (United States)

Cortisol "a steroid hormone" is known as a potential bio marker for psychological stress estimation and abnormality is indicative of many disorders. A simple, low-cost, label free sensor is required to detect Cortisol. Electrochemical immunosensors due to increased range, rapid detection, and sensitivity have been developed to detect Cortisol. The sensing performance is dependent on the functionality and electrical behavior of immobilizing matrix for high electron transport for signal amplification and loading of higher biomolecule.

In this work, nanostructured ZnO due to bio compatibility, chemical stability, high iso electric point, electrochemical activity, high electron mobility, ease of synthesis and high surface-to- volume ratio has been explored for electrochemical Cortisol immunosensing. ZnO nanostructures synthesized by Sonochemical method are used to immobilize Ant-Cortisol antibody (Anti-Cab). ZnO nanorods and nanoflakes are synthesized on Au/Si and ITO/PET as flexible substrates at ambient conditions. The selected area electron diffraction (SAED) and high resolution transmission electron microscopy (HRTEM) studies on the nanostructures showed that the nanostructures grown are single crystalline with orientation along [0001].Electro chemical detection is utilized for detection of Cortisol using anti- Cortisol antibodies (Anti-Cab) immobilized on ZnO nanostructures. The electrodes are characterized by using Scanning electron microscopy (SEM), Atomic force microscopy (AFM) and cyclic voltammetry (CV).

Electrochemical response studies of Anti-Cab/ZnO/Au immunoelectrode shows a linear relationship between the obtained current response and Cortisol concentration. The sensor exhibits a linearity from 1 pg/mL to 100 ng/mL, with a detection limit of 1 pg/mL and a sensitivity of 4μA/ (pg/mL) with a regression coefficient of 0.98. The obtained sensing performance is in physiological range. This developed sensor can be integrate with fluidic system for the automated sensing at point-of-care application

9107-31, Session 6

Real-time monitoring of food threats

Diana C. Vanegas-Gamboa, Univ. of Florida (United States) and Univ. del Valle (Colombia); Eric S. McLamore, Univ. of Florida (United States)

The ability to rapidly screen for food poisoning agents is a vital tool for maintaining a safe supply of high quality foodstuffs. Sensors and biosensors which target byproducts of key molecular interactions (e.g. toxins formed during contamination of meat by foodborne microorganisms) are currently one of the most successful approaches for meeting this need. Current advances in the field of nanotechnology have expanded the opportunities for the development of high fidelity sensing devices. Particularly, the unique properties of metal and carbon based nanocomposites such as vast surface area per unit mass and enhanced electro-catalysis, are allowing the development of new and improved electrochemical sensors. In this study, we have designed an electrochemical biosensor for real-time detection of specific biomarkers of bacterial metabolism which relate to meat spoilage. The biosensor was developed by assembling a 'sandwich' of nanomaterials and enzymes on a platinum-iridium electrode (1.6 mm tip diameter). The materials deposited on the sensor tip include amorphous platinum nanoculsters (Pt black), reduced graphene oxide, and ceria nanoparticles. Xanthine oxidase was encapsulated in laponite hydrogel and used for the biorecognition of hypoxanthine and xanthine (two molecules involved in the rotting of meat by spoilage microorganisms). The developed biosensor demonstrated good electrochemical performance with normalized sensitivity of 112.6 μA/mM cm2, response time of 5 sec, lower detection limit of 150 nM, and retained at least 88% of its activity after 7 days of continuous use.

9107-32, Session 8

Sensing more with less: new strategies for assays with quantum dots *(Invited Paper)*

W. Russ Algar, Eleonora Petryayeva, Miao Wu, Hyungki Kim, Cheryl Y. W. Ng, Erin Conroy, Melissa Massey, The Univ. of British Columbia (Canada)

The unique optical properties of semiconductor quantum dots (QDs) combined with Foerster resonance energy transfer (FRET) have attracted considerable interest for assay and biosensor development. In this presentation, recent efforts by our group to develop QD-FRET configurations for in vitro biosensing and point-of-care diagnostic platforms will be reported. The design and characterization of concentric FRET systems with multiple energy transfer pathways per QD will be described along with their applications for biosensing. Examples of concentric FRET systems suitable for multiplexed detection of enzyme activity, or for distinguishing between enzyme activity and concentration, will be presented, as will preliminary results with a self-contained probe for the detection of unlabeled nucleic acid targets. The importance of interfacial chemistry for engineering selectivity and sensitivity will be highlighted in these contexts. In addition, we will describe how QDs and the CMOS technology in cellphones and webcams can be utilized for simple, quantitative readout of paper test strips or multiplexed homogeneous assays for enzyme activity. In the former, cellulose paper substrates were modified with QD donors and acceptor-labeled biomolecular probes. Energy transfer rates between the QD and dye were enhanced within the paper matrix and enabled detection of enzyme activity at nanomolar concentrations through digital color imaging. This strategy can be extended to the simultaneous detection of the activity of three enzymes in homogenous assays. Progress in optimizing such assay formats will be discussed. Overall, the optical properties of QDs remain very promising for developing multiplexed probes for in vitro sensing and low-cost point-of-care assays.

9107-33, Session 8

Optical nanosystems for biomolecular recognition and reaction kinetics studies *(Invited Paper)*

Jong Hyun Choi, Purdue Univ. (United States)

There have been significant efforts in recent years in developing novel optical nanosystems for biomolecular detection and engineering. We have designed near-IR fluorescent single-wall carbon nanotubes with molecular recognition domain by functionalizing them with nucleic acids. With molecular recognition and self-assembly capabilities of oligonucleotides, we have studied target-receptor interactions at the nanoscale. The thermodynamics and kinetics of these interactions can be extracted by utilizing the signal transduction from the optical nanomaterials. Our system is a powerful and unique optical platform that allows one to probe and analyze biomolecular reactions both in ensemble and at single molecule level.

9107-34, Session 8

DNA-based switching using fluorescence resonance energy transfer *(Invited Paper)*

Susan Buckhout-White, Ellen R. Goldman, Jonathan C. Claussen, Mario G. Ancona, Igor L. Medintz, U.S. Naval Research Lab. (United States)

Structural DNA nanotechnology has developed profoundly in the last several years from development of new shapes and building methodologies, to truly employing these materials for molecular scaffolding towards the implementation of functional devices. To this end, we have developed a three-arm DNA switch (TADS) where the linkage between each arm can be physically detached and replaced using toehold mediated strand displacement. The TADS is also designed such that different linker lengths can be used independent of one another, such that the switch can take on a variety of characteristic shapes. Alone, the switch has little functionality apart from demonstration of a large array of permutations, with just three variables. However, when this system is coupled with a unique fluorescent dye attached to each arm that is FRET active in ensemble with all three dyes, as well as in individual pairs, the physical switch combines with the functionality of an optical switch to impart a great amount of versatility and function. As a logic based system, the TADS employs three potential unique sensing areas. Depending on the lengths of the linkers used, the logic characteristics of the TADS can change, permitting a variety of multiplexed sensing modalities, within the same system. We describe here the range of logic that can be produced from this three input system and how this may be able to translate to a highly modular sensor design.

9107-35, Session 8

Biomolecular logic systems: applications to biosensors and bioactuators *(Invited Paper)*

Evgeny Katz, Clarkson Univ. (United States)

The talk will outline the conceptual foundations of the novel approach to biosensing and bioactuating based on multi-step processing of biochemical signals through biocatalytic/biorecognition processes, adapting ideas recently developed in the field of bioelectronics and biocomputing (biomolecular logic). Biomolecular computing is an emerging field of unconventional computing that attempts to process information with biomolecules and biological objects using digital logic. Enzymatic systems which involve biocatalytic reactions utilized for information processing will be exemplified. Extensive ongoing research in biocomputing, mimicking Boolean logic gates has been motivated by potential applications in biotechnology and medicine. Novel biosensors digitally processing

multiple biomarker signals produce a final output in the form of YES/NO response through Boolean logic networks composed of biomolecular systems. The biocomputing approach applied to biosensors leads to a high-fidelity biosensing compared to traditional single-analyte sensing devices. By processing complex patterns of multiple physiological biomarkers, such multi-signal digital biosensors should have a profound impact on the rapid diagnosis and treatment of diseases, and particularly can provide timely detection and alert of medical emergencies (along with immediate therapeutic intervention). The novel biosensing concept has been exemplified with the systems for logic analysis of various injuries, including soft tissue injury, traumatic brain injury, liver injury, abdominal trauma, hemorrhagic shock and oxidative stress. Overall, integration of bioelectronics, biocomputing, materials science, and bionanotechnology resulted in the novel "smart" bioelectronic systems for medical, environmental and homeland security applications. The recent advances in this rapidly developing research area will be discussed.

9107-36, Session 8

Creating bionanophotonic logic devices and monitoring enzyme kinetics with quantum dot bioconjugates *(Invited Paper)*

Jonathan C. Claussen, U.S. Naval Research Lab. (United States); Niko Hildebrandt, Institut d'Électronique Fondamentale (France); Kimihiro Susumu, Mario G. Ancona, Igor L. Medintz, U.S. Naval Research Lab. (United States)

Luminescent semiconductor nanocrystals or quantum dots (QDs) hold tremendous promise for in vivo biosensing, cellular imaging, theranostics, and smart molecular sensing probes due to their small size and favorable photonic properties such as resistance to photobleaching, size-tunable PL, and large effective Stokes shifts. Herein we demonstrate how QD-based bioconjugates can be used for both complex molecular logic and mobile enzyme carriers. First, we demonstrate how Boolean Logic gates (e.g., AND/OR gates) and more complex combinatorial and sequential logic circuits (e.g., half-adder, half-substractor, 2:1 multiplexer, 1:2 demultiplexer, and keypad lock) can be developed by precisely manipulating the ratio of immobilized fluorescent dye (Alexa Fluor A647) and long lifetime luminescent terbium III complexes (Tb) around a central QD (625 nm) with His6-labeled peptides. Multiple Förster resonance energy transfer (FRET) pathways occur as the QD acts as an acceptor and donor between the Tb and A647 respectively at distinct time intervals—enabling rich, temporally varying photoluminescence emission profiles that can be converted into photonic logic gate/circuit signals. Second, we demonstrate how the behavior of immobilized enzymes (i.e., alkaline phosphatase) behaves on distinctly sized QDs. Enzyme-substrate kinetics is analyzed both experimentally and computationally while the enzyme packing density and spatial arrangement is controlled. These two distinct studies highlight the potential for QD-based bioconjugates in multiplexed in vivo biodetection and biosensing for disease diagnostics and treatment as well as elucidate the advantages of enzyme-nanoparticle immobilization for potential use in batch chemical reactions and advanced "nanomotor" applications.

9107-37, Session 9

Peptide-based protein capture agents with high affinity, selectivity, and stability as antibody replacements in biodetection assays

Matthew B. Coppock, U.S. Army Research Lab. (United States); Blake Farrow, California Institute of Technology (United States); Amethist S. Finch, U.S. Army Research Lab. (United States); Bert Lai, Indi Molecular (United States); Deborah A. Sarkes, U.S. Army Research Lab. (United States); James R. Heath, California Institute of Technology (United States); Dimitra N. Stratis-Cullum, U.S. Army Research Lab. (United States)

Current biodetection assays that employ monoclonal antibodies as primary capture agents exhibit limited fieldability, shelf life, and performance due to batch-to-batch production variability and restricted thermal stability. In order to improve upon the detection of biological threats in fieldable assays and systems for the Army, we are investigating protein catalyzed capture (PCC) agents as drop-in replacements for the existing antibody technology through iterative in situ click chemistry. The PCC agent oligopeptides are developed against known protein epitopes and can be mass produced using robotic methods. In this work, a PCC agent under development will be discussed. The performance, including affinity, selectivity, and stability of the capture agent technology, is analyzed by immunoprecipitation, western blotting, and ELISA experiments. The oligopeptide demonstrates superb selectivity coupled with high affinity through multi-ligand design, and improved thermal, chemical, and biochemical stability due to non-natural amino acid PCC agent design.

9107-38, Session 9

PPy/PMMA/PEG-based sensor for low-concentration acetone detection

Ali Daneshkhah, Sudhir Shrestha, Mangilal Agarwal, Kody Varahramyan, Indiana Univ.-Purdue Univ. Indianapolis (United States)

A polymer pallet-based sensor device comprised of polypyrrole (PPy), polymethyl methacrylate (PMMA) and polyethylene glycol (PEG), its fabrication methods, and the experimental results for low-concentration acetone detection will be presented. The design consists of a double layer pallet, where the top layer consists of PPy/PMMA and the bottom layer is composed of PPy/PMMA/PEG. Both sets of material compositions are synthesized by readily realizable chemical polymerization techniques. The mechanism of the sensor operation is based on the change in resistance of PPy and the swelling of PMMA when exposed to acetone, thereby changing the resistance of the layers. The resistances measured on the two layers, and across the pallet are taken as the three output signals of the sensor. As the PPy/PMMA and PPy/PMMA/PEG layers respond differently to acetone, as well as to other volatile organic compounds and water, it will be demonstrated that the three output signals can allow the presented sensor to have a better sensitivity and selectivity than previously reported devices. Preliminary experimental results with PPy/PMMA and PPy/PMMA/PEG layers respectively show a 3.4% increase and a 3.9% decrease in resistance, when 400 ppm of acetone is introduced in the test chamber. Additional sensor results, as well as degradation analysis from ongoing experiments, will be presented and discussed. The reported acetone sensor is applicable for biomedical and other applications.

9107-39, Session 9

Design of LWIR crystal and AOTF for compositional analysis of asteroid

Narsingh B. Singh, Bradley Arnold, L. D. Topoleski, Ronghui Ma, Brian Cullum, Univ. of Maryland, Baltimore County (United States); Narasimha S. Prasad, NASA Langley Research Ctr. (United States); Dennis Suhre, Milton Gottlieb, DRS Scientific Inc. (United States)

Design of crystal and AOTF along with AOTF based chemical detection will be described.

9107-40, Session 9

Physical vapor transport growth of lead tin selenide for MWIR detectors

Narsingh B. Singh, Univ. of Maryland, Baltimore County (United States); Narasimha S. Prasad, NASA Langley Research Ctr. (United States); Philip DiPaula, Pietro Strobbia, Bradley Arnold, Lisa Kelly, Brian Cullum, Univ. of Maryland, Baltimore County (United States)

There is a strong need for the high operating temperature (HOT) detectors for the MWIR and LWIR regions. Lead salts are excellent candidates have great potential for their applications especially for space systems.

9107-41, Session 10

Low-power MEMS acceleration sensors for mild-TBI early warning

Ryan R. Knight, David Lunking, Brian Isaacson, U.S. Army Research Lab. (United States); Larry Thomas, TechniMagic, Inc. (United States); Christopher J. Morris, Luke J. Currano, U.S. Army Research Lab. (United States)

A novel three-axis acceleration threshold sensor has been developed as an early warning system for potential mild traumatic brain injury (mTBI) and traumatic brain injury (TBI) events. The wearable sensor package fits the earbud form factor (5mm diameter) and operates in an ultralow power state until an impact acceleration event occurs. Eight normally open three-axis acceleration threshold switches ranging in threshold sensitivity, nominally 30-300g's(1-g is Earth's gravitational acceleration), detect impact through switch closure and the electronics process and transmits the data package via Bluetooth. Post processing via handheld smartphone and or PC will enable the end user to determine whether medical treatment is necessary. The mTBI and TBI sensor pushes the state-of-the-art in both form factor and battery life. Preliminary battery life shows that the sensors can detect and transmit up to five mTBI-like events over a month period of operational time before recharging. mTBI and TBI from blast or impact shocks is a continuing problem of primary importance to the DoD. Continuous, easy to use monitoring will enable immediate medical attention after a potentially mTBI or TBI inducing event, as well as reduce the risk for second-impact syndrome (SIS).

9107-42, Session 10

Control channels in the brain and their influence on brain executive functions

Qinglei Meng, Fow-Sen Choa, Univ. of Maryland, Baltimore County (United States); Elliot Hong, Univ. of Maryland School of Medicine (United States); Zhiguang Wang, Mohammad Islam, Univ. of Maryland, Baltimore County (United States)

In a computer network there are distinct data channels and control channels where massive amount of visual information are transported through data channels but the information streams are routed and controlled by intelligent algorithm through "control channels". Recent studies on cognition and consciousness have shown that the brain control channels are closely related to the brainwave beta (14-40 Hz) and alpha (7-13 Hz) oscillations. The high-beta wave is used by brain to synchronize local neural activities and the alpha oscillation is for desynchronization. When two sensory inputs are simultaneously presented to a person, the high-beta is used to select one of the inputs and the alpha is used to deselect the other so that only one input will get the attention. In this work we demonstrated that we can scan a person's brain using binaural beats technique and identify the individual's preferred control channels. The identified control channels can then be used to influence the subject's brain executive functions. In the experiment, an EEG measurement system was used to record and identify a subject's control channels. After these channels were identified, the subject was asked to do Stroop tests. Binaural beats was again used to produce these control-channel frequencies on the subject's brain when we recorded the completion time of each test. We found that the high-beta signal indeed speeded up the subject's executive function performance and reduced the time to complete incongruent tests, while the alpha signal didn't seem to be able to slow down the executive function performance.

9107-43, Session 10

Rehabilitation and motor learning through vibrotactile feedback

Roshan Panchanathan, Univ. of California, Berkeley (United States); Jacob Rosenthal, HeatSync Labs. (United States); Troy McDaniel, Arizona State Univ. (United States)

Until now, the norm for motor skill training has been through group instruction, due to the fact that it is both cost and time effective for the instructor. This applies even in rehabilitation, where groups of patients are taken through general exercises to maximize the clientele. Then, when the student or patient goes home, they are unable to receive proper feedback regarding the repetition of the desired exercises. This hinders each individual from achieving what they would if they were learning in a private one-on-one setting. The proposed system is a wearable device that offers real-time feedback for inputted goal movements. The instructor/therapist inputs goal joint angles and movements for the user and adapts the values over time for continued progress. Through a systematic evaluation, intuitive placements for the vibration motors were determined to effectively deliver feedback regarding joint angles and the speed of movements. This device, upon further testing, could be expanded to the whole body. We also introduce a flexible haptic display using a commercial LED strip that has been modified by attaching pancake style vibration motors along the strip for feedback. The flexible display does not require external microcontrollers to enable or disable motors, and may be expanded to the whole body.

9107-44, Session 11

Dynamic tissue phantoms and their use in assessment of a non-invasive optical plethysmography imaging device

Jeffrey E. Thatcher, Kevin D. Plant, Darlene King, Spectral MD™ (United States); Ken Block, Ken Block Consulting (United States); Wensheng Fan, J. Michael DiMaio, Spectral MD™ (United States)

Non-contact photoplethysmography (PPG) has been explored as a method to provide low-cost and non-invasive medical imaging for a variety of near-surface pathologies. For pre-clinical evaluation of PPG imaging a tissue phantom was developed consisting of an elastic vessel phantom combined with a gelatin soft-tissue phantom. First the stress-strain relationship of the vessel phantom was characterized to determine a fluid flow pressure loop that mimicked the small change in blood vessel volume during the regular heart beat in the human body. To mimic blood, a motility standard containing microspheres and an IR absorbent dye was selected. Complete phantoms were synthesized by embedding the vessel phantom in a gelatin-intralipid hydrogel and pumping the motility standard with a peristaltic pump. Two imaging systems were evaluated using these phantoms including a non-contact PPG imager, and a laser Doppler imager (LDI). Results indicate there was agreement across these systems in detecting the frequency of the phantom's pulse wave. As the tissue-volume change was increased the signal-to-noise ratio (SNR) increased sinusoidally for the PPG imager, while the increase was linear for LDI. When the vessel phantom was buried 8.0 mm beneath the gelatin phantom material, the PPG imager could detect fluid flow and produce images while the LDI system could not despite both systems emitting a similar near-IR wavelength. These results demonstrate the optical and dynamic fluid properties of the tissue

phantoms could be easily modulated and were effective for evaluating the SNR, pulse frequency, and spatial resolution of two non-invasive bloodflow imaging systems.

9107-45, Session 11

Characterization of tissue-simulating polymers for photoacoustic vascular imaging

William C. Vogt, T. Joshua Pfefer, U.S. Food and Drug Administration (United States)

Photoacoustic tomography (PAT) is a maturing imaging technique which combines optical excitation and acoustic detection to enable deep tissue sensing for biomedical applications. Optical absorption provides biochemical specificity and high contrast while ultrasonic detection provides high spatial resolution and penetration depth. These characteristics make PAT highly suitable as an approach for vascular imaging and blood gas measurements. However, standard testing methods are needed in order to characterize and compare the performance of these systems. Tissue-mimicking phantoms are commonly used as standard test samples for imaging system development and evaluation due to their repeatable fabrication and tunable properties. The multi-domain mechanism behind PAT necessitates development of phantoms that accurately mimic both acoustic and optical properties of tissues. While a wide variety of materials have been used in prior studies, from gelatin and agar hydrogels to silicone, published data indicates that poly(vinyl alcohol) (PVA) cryogels and poly(vinyl chloride) plastisol (PVCP) most closely simulate tissue optical and acoustic properties while also providing superior longevity and stability. Critical acoustic properties of both PVA and PVCP phantoms, including sound velocity and attenuation, were measured using acoustic transmission measurements at multiple frequencies relevant to typical PAT systems. Measurements of optical absorption and scattering coefficients of matrix materials with and without biologically relevant scatterers and hemoglobin-simulating chromophores were performed over wavelengths from 600 to 1100 nm. Both PVA and PVCP demonstrate strong potential as the basis of high-fidelity polymer phantoms for developing and evaluating PAT systems for vascular imaging.

9107-46, Session 11

Characterization of endogenous species in tissues using non-resonant multiphoton photoacoustic spectroscopy

Sudhir Dahal, Univ. of Maryland, Baltimore County (United States)

It has been shown that non-resonant multiphoton photoacoustic spectroscopy (NMPPAS) is capable of differentiating between excised flash-frozen brain tumor (grade III astrocytoma) and healthy tissue has with over 99% accuracy. This technique has the potential to be used as an optical biopsy technique for margining brain tumors during surgery.

Characterization of NMPPAS in terms of the depth at which excitation of the sample can occur via two-photons, determination of spatial resolution, and analyzing individual endogenous species responsible for resulting NMPPAS spectra were studied. These characterization studies were carried out using tissue phantoms that were made to mimic the light scattering properties of real brain tissues. Depth characterization measurements revealed that NMPPAS signals can be generated and detected from depths of greater than 1.3 cm, which is sufficient for most brain tumor margining applications. The lateral spatial resolution for such NMPPAS measurement was shown to be approximately 50 μm. In addition, endogenous species such as NAD+/NADH, flavins and hemoglobin were analyzed to understand their contribution to the NMPPAS spectra in the optical diagnostic window (700nm-1100nm), and to understand how the key endogenous species affect NMPPAS signal. This will ultimately lead towards the deconvulation of NMPPAS spectra of brain tumor tissues and healthy brain tissues.

9107-47, Session 11

High-resolution all-optical photo acoustic imaging system for remote interrogation of biological specimens

Ashwin Sampathkumar, Riverside Research Institute (United States)

Conventional photoacoustic imaging (PAI) employs light pulses to produce a photoacoustic (PA) effect and detects the resulting acoustic waves using an ultrasound transducer acoustically coupled to the target tissue. The resolution of conventional PAI is limited by the sensitivity and bandwidth of the ultrasound transducer. An all-optical versatile PAI system has been developed for characterizing ex vivo and in vivo biological specimens. The system employs non-contact interferometric detection of the acoustic signals that overcomes limitations of conventional PAM. A 532-nm pump laser with a pulse duration of 5 ns excited the PA effect in tissue. Resulting acoustic waves produced surface displacements that were sensed using a 532-nm continuous-wave (CW) probe laser in a Michelson interferometer with a GHz bandwidth. The pump and probe beams were coaxially focused using a 50X objective giving a diffraction-limited spot size of 0.48 μm. The phase-encoded probe beam was demodulated using a homodyne interferometer. The detected time-domain signal was time reversed using k-space wave-propagation methods to produce a spatial distribution of PA sources in the target tissue. Performance was assessed using 3D PA images of ex vivo porcine skin and retina specimens, human tooth samples and cell assays. A minimum peak surface displacement sensitivity of 0.19 pm was measured. The all-optical PAI system is well suited for assessment of retinal diseases skin burns, section less histology and pressure or friction ulcers.

9107-48, Session 12

Spherical drug delivery device with a radial modulated difussivity with lateral discharge through a thin ring

Natalia A. Gutierrez, Univ. EAFIT (Colombia)

The diffusion rate of a spherical drug delivery device was analyzed using a Laplace transform-based method. The three-dimensional model represented a pharmaceutical agent distributed, not uniformly, in a polymeric matrix. Molecules could only be transferred to the outside of the matrix through a thin spherical sector of the device. A closed-form solution was obtained to help study the effects of difussivity parameters and geometries on the cumulative amount of drug released. The latter variable increased with the mass transfer and diffusion function and decreased with any increment in the device's length.The solution obtained was in terms of the Legendre polynoms, and developed using the Maple software. It is expected that the results presentend help to the future design of devices in pharmaceutical engineering.

9107-49, Session 12

Analytical solution of a model for shrinking and expanding drug-loaded microspheres

Daniela D. B. M. Bolaños Marin, Univ. EAFIT (Colombia)

The dynamics of shrinking and expanding drug-loaded microspheres were studied using a diffusion equation in spherical coordinates and with a radially modulated diffusivity. A movable boundary condition that represents the shrinking or expanding was incorporated as a convection term in the original diffusion equation. The resulting convective-diffusive problem with radially modulated diffusivity was solved using Laplace transform techniques with the Bromwich integral, the residue theorem and special functions. Analytical solutions in the form of infinity series of special functions were derived for the general case of shrinking or expanding microspheres and some particular kinetics expressions, namely linear growth, exponential swelling and exponential shrinking. All computations were made using computer algebra, specifically Maple. Some simulations were made in the case of microspheres with fastswelling kinetics released their therapeutic cargo at a relatively slow rate in the first two cases. The analytical results were used to analyze insulin transport through spherical Ca-alginate beads. A good agreement was noted between predicted and experimental data. As future line of investigation, it is proposed the analysis of models with boundary condition that shows the memory effect. It is expected that the obtained analytical results could be very important in pharmaceutical engineering.

9107-50, Session 12

Analytical solution for the diffusion model of transdermal patches

Felipe Diaz Jaramillo, Univ. EAFIT (Colombia)

Transdermal patches are used in medicine to deliver a specific amount of medication through the skin and into the bloodstream, and then to the injury that will be treated. The diffusion process involved in this method was modeled using cartesian coordinates and cylindrical coordinates, and they were solved using Laplace transformation, Bromwich integral and the residue theorem. The solution obtained in cartesian coordinates was given in terms of Fourier series, and the solution obtained in cylindrical coordinates was given in terms of Bessel functions. The cumulative amounts of drug released at time t were calculated for both models and are represented as infinite series of decreasing exponentials. It's expected that the analytic results obtained will be useful for pharmaceutical engineering.

9107-51, Session 12

Drug diffusion in a stratum corneum with diffusivity spatially modulated

Isabel Montoya Arroyave, Univ. EAFIT (Colombia)

A diffusion and injection model of a drug in a stratum corneum with diffusivity spatially modulated is formulated and solved analytically using computer algebra. The model is developed using one-dimensional diffusion equation with a diffusivity which is a function of position in the stratum corneum and with a boundary condition at the base of the stratum corneum which represents a sump exponentially activated. The model is solved analytically by the method of the Laplace transform, with Bromwich integral and residue theorem. The concentration profile of the drug in the stratum corneum is expressed as an infinite series of Bessel functions. The corresponding AUC is expressed as the sum of a Bessel function with an infinite series of exponential decreasing. All computations were performed using computer algebra software, specifically Maple. The analytical results obtained are important for understanding and improving currents therapies of transdermal drug application. For future research it is interesting to consider more general models of spatial modulation of the diffusivity and the possible application of other computer algebra software such as Mathematica and Maxima.

9108-8, Session 1

Effects of food surface topography on phage-based magnetoelastic biosensor detection

Shin Horikawa, Yating Chai, Ruiting Zhao, Howard C. Wikle III, Bryan A. Chin, Auburn Univ. (United States)

Phage-based magnetoelastic (ME) biosensors have recently proven useful in rapidly and inexpensively detecting food surface contamination. These biosensors are label-free, wireless, mass-sensitive biosensors and can be placed directly on food surfaces to detect the presence of target pathogens. Previously, millimeter-scale strip-shaped ME biosensors have been used to demonstrate direct detection of Salmonella Typhimurium on various fresh produce surfaces, including tomatoes, shell eggs, watermelons, and spinach leaves. Since the topography of these produce surfaces are different, and the biosensor must come into direct contact with Salmonella bacteria, food surfaces with large roughness and curvatures (e.g., spinach leaf surfaces) may allow the bacteria to avoid direct contact, thereby avoiding detection. The primary objective of this paper is, hence, to investigate the effects of food surface topography on the detection capabilities of the biosensors. Spinach leaf surfaces were selected as model surfaces, and detection experiments were conducted with differently sized micron-scale biosensors. Spinach leaf roughness and curvatures of both adaxial (top) and abaxial (underside) surfaces were measured using a laser confocal microscope. The experimental results showed that in spinach as the sensor is made smaller, the physical contact between the biosensors and bacteria are improved. Smaller sensors thereby enhance detection capabilities. When proper numbers of biosensors were used, micron-scale biosensors were found to yield improved limits of detection over previously investigated millimeter-scale biosensors.

9108-9, Session 1

Real-time bacteria detection on fresh food surfaces with a microfabricated coil detector and magnetoelastic biosensors

Yating Chai, Shin Horikawa, Howard C. Wikle III, Ruiting Zhao, Bryan A. Chin, Auburn Univ. (United States)

As part of the ongoing efforts to secure the safety of our food supply, the role of pathogen detection technologies has become vital. This research demonstrates a newly developed microfabricated coil that allows food surfaces to be scanned for real-time detection of surface bacterial contamination. We have previously reported the possible use of magnetoelastic (ME) biosensors for the detection of pathogenic bacteria on food surfaces. The ME biosensor is composed of a freestanding, strip-shaped ME resonator coated with E2 phage, which is engineered to specifically bind with Salmonella Typhimurium. When the ME biosensor comes into contact with target bacteria cells, the bacteria are captured and bound to the biosensor's surface. The bound bacteria cause the mass of the biosensor to increase, resulting in a decrease in the resonant frequency. The frequency change is directly proportional to the additional mass of the bacteria attached to the biosensor surface. This new detection system consists of a planar spiral coil that excites and measures the resonant frequency of freestanding ME biosensors on the surface of fruits and vegetables. No longer do the ME biosensors need to be retrieved from the fresh food surfaces and placed inside a solenoid coil for measurement. In addition, this microfabricated coil can largely improve the detector's standoff distance, which enables the detector to evaluate fruits and vegetables with surfaces of large curvature and roughness. Furthermore, the ability to simultaneously detect multiple sensors on surfaces has been demonstrated.

9108-10, Session 1

Pulsed excitation system to measure the resonant frequency of magnetoelastic biosensors

Hong Xie, Yating Chai, Shin Horikawa, Howard C. Wikle III, Bryan A. Chin, Auburn Univ. (United States)

A pulsed excitation system was designed to excite resonance in micron-scale magnetoelastic (ME) biosensors that are used detect foodborne pathogens. The ME biosensor is a mass sensitive device whose resonant frequency is inversely proportional to its mass and length. A biorecognition probe coated onto the ME platform is used to capture and bind targeted pathogens. A pulsed excitation system offers a simple method to excite ME biosensors to resonate, eliminating the need for expensive laboratory benchtop measurement equipment. With this system, a square-wave pulse of current is applied to a solenoid coil to generate a pulsed magnetic field, exciting the ME biosensor to vibrate longitudinally with damped, ring-down vibration behavior. A separate pick-up coil is used to sense the vibration of the biosensor by converting its magnetic flux into an electrical current. A signal conditioning circuit was designed and built to amplify the current signal from the pickup coil so that the frequency change due to the binding of pathogens can be easily determined. ME biosensors as small as 200 µm long were used with this system exhibiting a resonant frequency of approximately 10.828 MHz. The effect of the excitation pulse current on the biosensor's vibration characteristics (resonant frequency, amplitude, Q-factor) was studied. As a proof-in-concept experiment, the measurement system was used in combination with micron-scale ME sensor platforms that were coated with JRB7 phage to detect different concentrations of Bacillus anthracis spores. A statistically significant difference for all concentrations of 5 ? 102 spore/ml and higher was obtained.

9108-18, Session 1

Self-propelled, phage-based magnetoelastic biosentinels for detection of pathogens in liquid

Ruiting Zhao, Yating Chai, Shin Horikawa, Howard C. Wikle III, Bryan A. Chin, Auburn Univ. (United States)

This paper investigates self-propelled, phage-based magnetoelastic (ME) biosentinels to detect pathogens in liquid. The ME biosentinels are designed to mimic white blood cells in the human body. These nature-inspired biosentinels are composed of an asymmetric ME resonator coated with a landscape phage that is specific for a pathogen of interest. When subjected to an externally applied time-varying magnetic pulse, the ME biosentinels are placed into mechanical resonance. The resultant resonating biosentinels can then autonomously move in liquid due to the net acting force and fluid-structure interactions. As soon as the sentinels find and bind with the target pathogen through the phage-based biomolecular recognition, a change in the biosentinel's resonant frequency occurs, and thereby the presence of the target pathogen can be detected. Modal analysis using the three-dimensional finite element method was performed to find the resonant frequency of asymmetric-shaped ME biosentinels with different sizes. In addition, the net force acting on the resonating biosentinels was calculated. With the calculated net force, the motion of the biosentinels in liquid was then simulated, and both dynamic simulation and experiment results showed the biosentinels can move autonomously in liquid and actively bind with the target pathogen. Proof-in-principle of the ME biosentinels detection has been demonstrated.

9108-1, Session Posters-Tuesday

Analytical model of contamination during the drying of cylinders of jamonable muscle

Isabel Montoya Arroyave, Univ. EAFIT (Colombia)

For a cylinder of jamonable muscle of radius R and length much greater than R; considering that the internal resistance to the transfer of water is much greater than the external and that the internal resistance is one certain function of the distance to the axis; the distribution of the punctual moisture in the jamonable cylinder is analytically computed in terms of the Bessel's functions. During the process of drying and salted the jamonable cylinder is sensitive to contaminate with bacterium and protozoa that come from the environment. An analytical model of contamination is presents using the diffusion equation with sources and sinks, which is solve by the method of the Laplace transform, the Bromwich integral, the residue theorem and some special functions like Bessel and Heun. The critical times intervals of drying and salted are computed in order to obtain the minimum possible contamination. It is assumed that both external moisture and contaminants decrease exponentially with time. Contaminants profiles are plotted and discussed some possible techniques of contaminants detection. All computations are executed using Computer Algebra, specifically Maple. It is said that the results are important for the food industry and it is suggested some future research lines.

9108-4, Session Posters-Tuesday

A hyperspectral imaging (HSI)-based approach for bio-digestate real time monitoring

Giuseppe Bonifazi, Silvia Serranti, Andrea Fabbri, Univ. degli Studi di Roma La Sapienza (Italy)

One of the key issues in developing Good Agricultural Practices (GAP) is represented by the optimal utilisation of fertilisers and herbicidal to reduce the impact of Nitrates in soils and the environment.

In traditional agriculture practises, these substances were provided to the soils through the use of chemical products (inorganic/organic fertilizers, soil improvers/conditioners, etc..), usually associated to several major environmental problems, such as: water pollution and contamination, fertilizer dependency, soil acidification, trace mineral depletion, over-fertilization, high energy consumption, contribution to climate change, impacts on mycorrhizas, lack of long-term sustainability, etc.. For this reason, the agricultural market is more and more interested in the utilisation of organic fertilisers and soil improvers. Among organic fertilizers, there's an emerging interest for the digestate, a sub-product resulting from Anaerobic Digestion (AD) processes. Several studies confirm the high properties of digestate if used as organic fertilizers and soil improver/conditioner. Digestate, in fact, is somehow similar to compost: AD converts a major part of organic nitrogen to ammonia, which is then directly available to plants as nitrogen. In this paper, new analytical tools, based on HyperSpectral Imaging (HSI) sensing devices, and related detection architectures, is presented and discussed in order to define and apply simple to use, reliable, robust and low cost strategies finalised to define and implement innovative smart detection engines for digestate characterization and monitoring. This approach being finalised to utilised this "waste product" as a valuable organic fertilizer, and soil conditioner, in a reduced impact and of an "ad hoc" soil fertilisation perspective. Furthermore, the possibility to contemporary utilize the HSI approach to realise a real time physical-chemical characterisation of agricultural soils (i.e. nitrogen, phosphorus, etc. detection) could allow to set up "real time" selective fertilization strategies finalised to realise a safer culture production.

9108-5, Session Posters-Tuesday

A model of freezing foods with liquid nitrogen using special functions

Martin Rodriguez, Univ. EAFIT (Colombia)

A food freezing model is analyzed analytically. The model is based on the heat diffusion equation in the case of cylindrical shaped food freezed by liquid nitrogen; and assuming that the thermal conductivity of the cylindrical food is radially modulated. The model is solved using the Laplace transform method, the Bromwich theorem, and the residue theorem. The temperature profile in the cylindrical food is presented as an infinite series of Bessel functions. All the required computations are performed with computer algebra software, specifically Maple. Using the numeric values of the thermal and geometric parameters for the cylindrical food, as well as the thermal parameters of the liquid nitrogen freezing system, the temporal evolution of the temperature in different regions in the interior of the cylindrical food is presented both analytically and graphically. The duration of the liquid nitrogen freezing process to achieve the specified effect on the cylindrical food is computed. The analytical results are expected to be of importance in food engineering and cooking engineering. As a future research line, the formulation and solution of freezing models with thermal memory is proposed.

9108-6, Session Posters-Tuesday

An analytically resolved model of a potato's thermal processing using Heun functions

Agustín Vargas Toro, Univ. EAFIT (Colombia)

A potato's thermal processing model is solved analytically. The model is formulated using the equation of heat diffusion in the case of a spherical potato processed in a furnace, and assuming that the potato's thermal conductivity is radially modulated. The model is solved using the method of the Laplace transform, applying Bromwich Integral and Residue Theorem. The temperatures' profile in the potato is presented as an infinite series of Heun functions. All computations are performed with computer algebra software, specifically Maple. Using the numerical values of the thermal parameters of the potato and geometric and thermal parameters of the processing furnace, the time evolution of the temperatures in different regions inside the potato are presented analytically and graphically. The duration of thermal processing in order to achieve a specified effect on the potato is computed. It is expected that the obtained analytical results will be important in food engineering and cooking engineering. It is proposed a future line of research along with the formulation and solution of models with thermal memory.

9108-7, Session Posters-Tuesday

Mathematical model for solar drying of potato cylinders with thermal conductivity radially modulated

Mariana Trujillo Arredondo, Univ. EAFIT (Colombia)

A mathematical model for drying potato cylinders using solar radiation is proposed and solved analytically. The model incorporates the energy balance for effects of the heat capacity of the potato, the radiation heat transfer from the potato toward the drying chamber and the solar radiation absorbed by the potato during the drying process. Potato cylinders are assumed to exhibit a thermal conductivity radially modulated. The method of the Laplace transform, with integral Bromwich and remainder theorem is applied and the analytic solution of the temperature profiles in the potato cylinder is derived in the form of an infinite series of Bessel functions. All computations are performed using computer algebra, Maple specifically. It is expected that the analytical results obtained will be useful in engineering and food industry. It suggests some future research lines as the adoption

of radial modulators broader thermal conductivity of potato cylinders and possible free software application Maxima analytical model computations.

9108-11, Session Posters-Tuesday

Rapid detection of chlorpyrifos pesticide residue concentration in agro-product using Raman spectroscopy

Sagar Dhakal, Yongyu Li, Yankun Peng, Leilei Zhang, Tianfeng Xu, China Agricultural Univ. (China)

Different chemicals are sprayed in fruits and vegetables before and after harvest for better yield and longer shelf-life of crops free of diseases. Cases of pesticide poisoning to human health are regularly reported due to excessive application of such chemicals beyond the prescribed limit for greater economic benefit. Different analytical technologies exist to detect pesticides in fruits and vegetables to detectable trace amount, but are expensive, sample destructive, and require longer processing time. This study explores the application of Raman spectroscopy for rapid and non-destructive detection of pesticide residue in agricultural products. Raman spectroscopy with laser module of 785 nm was used to collect Raman spectral information from the surface of Galla apples contaminated with different concentrations of commercially available organophosphorous (48% chlorpyrifos) pesticide. Apples within 15 days of harvest from same orchard were used in this study. The Raman spectral signal was processed by Savitzky-Golay (SG) filter for noise removal, Multiplicative Scatter Correction (MSC) for drift removal and finally polynomial fitting was used to eliminate the fluorescence background. The Raman spectral peak at 677 cm-1 was recognized as Raman fingerprint of chlorpyrifos. Presence of Raman peak at 677 cm-1 after fluorescence background removal was used to develop classification model (presence and absence of pesticide). The peak intensity was correlated with actual pesticide concentration from 21 apples tested with Gas Chromatography (GC) to develop pesticide concentration prediction model. Linear relation between pesticide concentration and Raman peak intensity was developed with correlation coefficient greater than 85%. Result shows that Raman spectroscopy is a promising tool for rapid, real-time and non-destructive detection of pesticide residue in agro-products.

9108-12, Session Posters-Tuesday

A portable detection instrument based on DSP for beef marbling

Tong Zhou, Yankun Peng, China Agricultural Univ. (China)

Beef marbling is one of the most important indexes to assess beef quality. The grade of beef marbling is a measurement of the fat distribution density in the rib-eye region. However quality grades of beef in most of the beef slaughtering house and enterprise depend on trainees using visual senses or comparing to the standard sample cards in China. This manual grading method demands not only great labor but also lacks the objectivity and accuracy. Aiming at the necessity of beef slaughtering house and enterprise, a beef marbling detection instrument was designed. The instrument involves CCD imaging techniques, digital image processing, DSP control and processing techniques and LCD screen display techniques. The TMS320DM642 digital signal processor of TI is the core to make full use of its high-speed data processing capabilities and real-time processing features. All process such as image acquisition, data transmission, image processing algorithms and display were implemented on this instrument for quick and non-destructive detection of beef marbling. Structure of the system, working principle, hardware device and software system were introduced in detail. Besides the characteristic of small bulk and being easy to taken, the instrument can detect the level of beef marbling reliably and correctly on various occasions.

9108-13, Session Posters-Tuesday

A portable device for rapid nondestructive detection of meat quality attributes

Wan Lin, Yankun Peng, China Agricultural Univ. (China); Caiping Wang, Xinjiang Yurun Co. (China)

Quality attributes of fresh meat will influence nutritional value and consumers' purchasing power. For detecting quality attributes of fresh meat, VIS/NIR technology can be a very useful method because reflectance spectrum reveals potential information of the sample. Although some online detection equipments have been developed, there still remains a need for devices that can be handheld. In order to meet the demand of inspection department for portable device, a rapid and nondestructive detection device for fresh meat quality based on ARM (Advanced RISC Machines) processor was designed. Working principal, hardware composition, software system and functional test were introduced. Hardware system consisted of ARM (Advanced RISC Machines) processing unit, light source and detection unit, spectral data acquisition unit, LCD (Liquid Crystal Display) touch screen display unit and the cooling unit. Linux operating system and quality parameters acquisition processing application were designed. This system has realized collecting spectral signal, storing data, displaying results on handheld device. The experimental result shows that this device can be a useful tool for detecting quality of meat and for helping processors to determine potential safety risks of food.

9108-14, Session Posters-Tuesday

Nondestructive detection of fresh pork comprehensive quality based on spectroscopy and support vector machine

Yuanyuan Liu, Yankun Peng, Leilei Zhang, Sagar Dhakal, China Agricultural Univ. (China)

Pork is one of the highly consumed meat item in the world. With growing improvement of living standard, concerned stakeholders including consumers and regulatory body pay more attention to comprehensive quality of fresh pork. Different analytical-laboratory based technologies exist to determine quality attributes of pork. However, none of the technologies are able to meet industrial desire of rapid and non-destructive technological development. Current study used optical instrument as a rapid and non-destructive tool to classify 56 24h-aged pork longissimusdorsi samples into two kinds of meat,normal meat (NM) and pale ,soft and exudative (PSE), on the basis of color, pH24 and water holding capacity. Optical system based on Vis/NIR spectral acquisition system (350 to 2500 nm) was self- developed in laboratory to acquire spectral signal of pork samples. Median smoothing filter (M-filter) and multiplication scatter correction (MSC) was used to removal spectral noise and signal drift. Support vector machine(SVM)prediction model was developed to classify the samples based on their comprehensive qualities. The resultsshowed that the classification model is highly correlated with the actual quality parameters with classification accuracy more than 85%.The system developed in this study being simple and easy to use, results being promising, the system can be used in meat processing industry for real time, non-destructive and rapid detection of pork qualities in future.

9108-16, Session Posters-Tuesday

Development of UVA and violet LED excitation lighting system for hyperspectral fluorescence line-scan imaging

Hoyoung Lee, Moon S. Kim, Agricultural Research Service (United States); Colm D. Everard, Univ. College Dublin (Ireland); Jong-Guk Lim, National Academy of Agricultural Science (Korea, Republic of)

In this paper, the excitation system for fluorescence line-scan imaging is developed to be equipped UVA and violet high power LED modules, which is able to emit UVA(365nm) and violet(400nm) radiation simultaneously or solely, and provides on/off control of a LED module via USB communication and the control panel. That performs more fluorescence emission on the fluorescence references than previous bulb-type UV lighting system by about 10 times.

9108-23, Session Posters-Tuesday

Detection of the total viable counts in chicken based on visible/near-infrared spectroscopy

Xiuying Tang, Yuan Long, Yankun Peng, Linlin Zhao, China Agricultural Univ. (China)

The total viable counts (TVC) in chicken have significant effects on food safety, which will make negative influence to the public when exceeding the standard seriously especially. The objective of this study was to detect the total viable counts of chicken breast. Forty chicken breast fillets in total used in the study were stored in a refrigerator at 4°C for 10 days. Each day four samples were taken out to test their total viable counts and acquire their visible/near infrared spectrum. The original spectral data of chicken breast fillet was processed by following four main steps: Savitzky-Golay smoothing method (S-G), standard normalized variate (SNV), model calibration and model evaluation. Finally three prediction models based on 400-1700nm, 400-1100nm and 980-1700nm were established using partial least squares regression (PLSR) method. Several statistical indicators such as root mean squared errors and correlation coefficients were calculated for determination of cross-validation, calibration and prediction respectively. As a result, the Rc, Rp and Rcv of the best model was as high as 0.92, 0.89 and 0.90. The results showed that visible-near infrared spectra was a potential technique to detect the total viable counts in chicken meat and the best spectral range for the establishment of the prediction model was 400-1100nm from which the best wavelengths would be chosen. This research provides the basis for development of inspection equipment that can be used in commercial poultry processing industry to reduce food safety risks.

9108-24, Session Posters-Tuesday

Lock-in phase imaging of near/mid infrared signals for the detection of bruise on fruit

Ghiseok Kim, Geonhee Kim, Korea Basic Science Institute (Korea, Republic of); Dae Yong Kim, Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of)

The feasibility of lock-in phase imaging was evaluated for the detection of bruise on fruits such as persimmon and pear. Bruise is one of mechanical damage which is usually difficult to be detected in early stage after harvested by conventional methods such as image process using CCD camera or manual sorting by human. Lock-in phase imaging of photo-luminescence and photo-thermal signals from fruits were achieved by highly sensitive near/mid infrared cameras. Measured photo-luminescence and photo-thermal signals were post-processed using a lock-in method which employs a periodic input energy to the fruit by a broad band halogen lamp. By applying the lock-in method to the photo-luminescence and photo-thermal signals from fruits, the detection sensitivity and signal to noise ratio were enhanced because of the phase-sensitive narrow-band filtering effects. The merits of lock-in phase imaging technique are the temperature sensitivity which range within μK and the dynamic characteristics which reduce a thermal blurring derived from the inhomogeneous infrared emissivity of material. In addition, the depth of bruise was estimated by implementing a photo-thermal theory to investigate the behavior of thermal waves on fruit under convective conditions. Results showed that the proposed lock-in phase imaging method of photo-luminescence and photo-thermal signals from fruit and depth estimation technique has a good potential as one of NDE methodology in order to evaluate a mechanical damage of fruit, especially in the early stage of bruise.

9108-28, Session Posters-Tuesday

Online measurement of sugar content of cherry tomato using VIS/NIR spectrometer

Hong-Suck Lee, Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of)

A VIS/NIR spectroscopic method with the spectral range of 470 – 1,150 nm with a 1.5 nm spectral resolution was used for online prediction of sugar content of cherry tomatoes. Spectra were acquired from a total of 300 samples of cherry tomatoes of two different varieties at 6 different maturity stages moving on the conveyer belt. A partial least square regression (PLSR) model with various preprocessing methods was developed to predict sugar content of cherry tomatoes. The actual sugar content of cherry tomatoes was measured by using a refractometer as a reference. The errors of the developed model were 0.02 °Brix for calibration and 0.16 °Brix for validation. Results show that the developed PLSR model has potential to predict sugar content with the online sorting system for cherry tomatoes.

9108-31, Session Posters-Tuesday

Evaluation of food freshness by surface acoustic wave sensor

Ki-Bok Kim, Korea Research Institute of Standards and Science (Korea, Republic of); Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of); Byounggab Lim, Master Korea Co., Ltd (Korea, Republic of)

In this study, the freshness of chicken meat was evaluated by a surface acoustic wave (SAW) sensor. Various gas components were analyzed during the storage day of chicken meat by using GC-MS (Gas chromatograph mass spectrometer). From the results of GC-MS analyses, as a freshness factor of chicken meat, acetaldehyde (CH_3CHO) was selected because of its rapid increase after 5 days. As a sensitive layer of the SAW sensor for evaluating the freshness of chicken meat, PDMS (polydimethylsiloxane) film was coated on the surface of SAW device between input and output inter-digital transducers (IDTs). The IDTs were fabricated on the surface of $LiNbO_3$ piezoelectric wafer by the standard photolithographic techniques. To analyze the performance of the fabricated SAW sensor with PDMS film, N_2 gas (carrier gas) and various concentrated CH_3CHO gases were mixed and fed into the SAW sensor with PDMS film. Since the phase shift of the SAW sensor increased with the increase of concentration of CH_3CHO, the developed SAW sensor showed good sensitivity and stability. The SAW sensor system for evaluating the freshness of chicken meat consisted of the voltage controlled oscillator, frequency counter, voltage regulator, LCD display, microprocessor, small chamber with SAW sensor and so on. Since the distinct frequency change of the developed SAW sensor was found during storage of the packaged chicken, evaluation of the freshness of packaged chicken will be possible.

9108-19, Session 2

Development of algorithms for senescence and quality detection on fluorescence images of peppers

Carlos Esquerre, Univ. College Dublin (Ireland) and Agricultural Research Service (United States); John R. Stommel, Agricultural Research Service (United States); Colm P. O'Donnell, Univ. College Dublin (Ireland); Moon S. Kim, Stephen R. Delwiche, Agricultural Research Service (United States)

Three replicates of green bell peppers and jalapeños peppers were sliced and sealed in modified atmosphere packing and cool stored (5 ?C) for different times (0, 7, 10, 14 and 21 days postharvest). Ultra violet (UV) and

violet (VL) fluorescence images were acquired immediately after opening the samples bags. Two high powered LED systems with excitation at 365 nm and 400 nm center wavelength for UV and VL images, respectively, separately illuminated the slices while corresponding emission images were acquired in the wavelength range of 464 – 799 nm. Chemometric algorithms (Principal Component Analysis and Partial Least Squares) and image processing methods (masking, thresholding, and morphological operations) were developed for senescence and quality detection in hyperspectral fluorescence images. Additionally, correlation analysis and scaled difference of sample spectra were investigated and compared with the chemometric approaches.

9108-20, Session 2

Hyperspectral imaging for unified safety inspection of poultry carcasses

Seung-Chul Yoon, Bosoon Park, Kurt C. Lawrence, William R. Windham, Kuanglin Chao, Chun-Chieh Yang, Moon S. Kim, Agricultural Research Service (United States)

This paper reports the development of a unified hyperspectral imaging system that can be used as a real-time online poultry carcass inspection instrument in poultry processing plants. In chicken processing plants in the United States, on-line carcass inspection of chickens is done using a visual (organoleptic) method by FSIS inspectors. The USDA-ARS researchers have developed hyperspectral/multispectral imaging methods and systems for detecting chicken carcasses with surface fecal matters or systemic disease (septicemia and toxemia). Although the hyperspectral imaging systems for disease or fecal detection were independently developed by two different ARS groups, the fundamentals of each imaging system were the same. The researchers adopted a line-scan hyperspectral image camera based on a dispersive spectrograph (400 nm - 900 nm) and a detector such as EMCCD and developed various hyperspectral and multispectral image processing algorithms to solve their detection problems. In this paper, we will report the development of a prototype of a common imaging platform doing simultaneous inspections of fecal matters and systemic disease on chicken carcasses. This common imaging platform acquires spectral images from five discrete wavelengths centered at 517, 565, 580, 600 and 620 nm. An application software program, written in MS-Visual C++, processes two different detection algorithms and makes a final decision about wholesomeness of each chicken carcass. We will demonstrate the feasibility of a high-speed hyperspectral machine vision system for inspecting wholesomeness of poultry carcasses, which can be also expanded to simultaneously inspect other quality characteristics such as bruises and feathers.

9108-27, Session 2

Spectral imaging analysis for determination of viability of vegetable seeds

Hyungjin Bae, Chungnam National Univ. (Korea, Republic of); Moon S. Kim, USDA Agricultural Research Service (United States); Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of)

Conventional spectroscopic measurement for seed sample is single seed basis, which has a limitation for the fast measurement for massive amount of specimens. Hyperspectral imaging technique provides both spatial and spectral information simultaneously could be an ideal tool for the measurement of a massive number of seed samples. In this study, hyperspectral short wave reflectance imaging technique was used to determine viability of various vegetable seeds. Spectral images combined with chemometrics such as partial least square analysis showed good potential for the evaluation of viability of vegetable seeds.

9108-29, Session 2

Calibrations transfer method for use with multiple hyperspectral imaging systems *(Invited Paper)*

Kurt C. Lawrence, William R. Windham, Seung-Chul Yoon, Bosoon Park, Agricultural Research Service (United States)

For any spectroscopic model to be used in a real-world situation, protocols must be implemented to ensure that a chemometric model, developed on a primary spectroscopic instrument,

will also be valid when used on data collected from a secondary spectroscopic instrument. For standard spectroscopic instruments, these protocols were developed years ago and are commonly implemented into commercial instruments. However, for hyperspectral imaging systems, these protocols are not yet fully developed. Thus, there is a need for an enhanced calibration method that will allow prediction models to be transferred from one system to another. This protocol will require that a specific calibration panel with known absolute reflectance values at every wavelength be used to calibrate each hyperspectral imaging system. Additionally, identical data pretreatment methods will have to be applied to each system and the data from secondary systems (not used to develop the original prediction model) will have to be wavelength-resampled so that all data align across instruments. In this research, a primary hyperspectral imaging system was calibrated against a known 40% reflectance standard. Two different calibration and model transfers methods were then compared. The first method utilized a simple nominal-value calibration panel on both the primary and secondary systems (i.e. 40% nominal for all wavelengths on both systems). The second method utilized NIST-traceable values provided with each calibration panel (one for primary and one for secondary) in the calibration equation. Data were also wavelength resampled. Results were evaluated by imaging an independent, standard gradient reference panel on each system. To further test the protocol, several agar plates with pathogenic and non-pathogenic bacteria growing were imaged on two different hyperspectral imaging systems and the results were compared. With the NIST-traceable method, the results were very similar for each system with the primary system having an overall accuracy of 100% while the secondary system had an overall accuracy of 99.6%. Thus, the feasibility of a hyperspectral imaging calibration transfer protocol was confirmed.

9108-15, Session 3

Using NOAA/AVHRR based vegetation health indices and principal component regression method for estimation of Aman rice yield in Bangladesh.

Mohammad Nizamuddin, Kawsar A. Akhand, Leonid Roytman, The City College of New York (United States); Felix Kogan, Mitch Goldberg, National Environmental Satellite, Data, and Information Service (United States)

Rice is the most important food crop in Bangladesh because the people of Bangladesh has its own tradition of foods and in the sense of food habits rice is the main food in their daily life. To ensure food security, to fulfill the total demand of rice the government of Bangladesh always pay utmost priority in rice yield and accordingly maintain a special allocation in national budget. Bangladesh is known to be the land of natural disasters it suffers floods, cyclones, lack of rainfall and lot of natural calamities but due to government subsidies in agricultural sectors rice production is almost achieved the domestic demand. Aman is one of the main rice varieties and second largest food crop in respect of the volume of production in Bangladesh. In this paper we have tried to predict aman rice yield in Bangladesh using official statistics of rice yield with real time acquired satellite data from Advanced Very High Resolution Radiometer (AVHRR) sensor and Principal Component Regression (PCR) method was used to construct a model. We used co-located statistical and satellite data for the same period for model development and validation. A strong correlation was found between aman rice yield and vegetation health indices (VCI).

The predicted value from this model was compared to actual statistical rice yield showed that the error of prediction is less than 10% and the prediction is done at least two to three months before the aman rice harvested. Therefore, this model can be considered as a potential tool for estimating aman rice as satellite data are inexpensive and readily available that also helps the government to take right decision and planning.

9108-21, Session 3

Hyperspectral fluorescence imaging coupled with multivariate image analysis techniques for contaminant screening of leafy greens

Colm D. Everard, Univ. College Dublin (Ireland); Moon S. Kim, Hoyoung Lee, Agricultural Research Service (United States)

The production of contaminant free fresh fruit and vegetables is needed to reduce foodborne illnesses and related costs. Leafy greens grown in the field can be susceptible to fecal matter contamination from uncontrolled livestock and wild animals entering the field. Pathogenic bacteria can be transferred via fecal matter and several outbreaks of E.coli O157:H7 have been associated with the consumption of leafy greens. This study examines the use of hyperspectral fluorescence imaging coupled with multivariate image analysis to detect fecal contamination on Spinach leaves (Spinacia oleracea). Hyperspectral fluorescence images from 464 to 800 nm were captured; ultra violet excitation was supplied by two LED-based line light sources at 370 nm. Key wavelengths and algorithms useful for a contaminant screening optical imaging device were identified and developed, respectively. A non-invasive screening device has the potential to reduce the harmful consequences of foodborne illnesses.

9108-22, Session 3

Differentiating glyphosate resistant and glyphosate sensitive Italian ryegrass using hyperspectral imagery

Matthew A. Lee, Yanbo Huang, Agricultural Research Service (United States)

Standard weed control methods prefer glyphosate based herbicides. Italian ryegrass (Lolium multiflorum) has developed resistance to glyphosate. The identification of glyphosate resistant weeds is critical because different techniques must be used to control their spread before they lower agricultural yield. In this research, we investigate the use of high spatial resolution hyperspectral imagery of individual plants to extract precise spectral curves derived from the whole plant to determine if the plant is glyphosate resistant (GR) or glyphosate sensitive (GS). The data set consists of about 200 plants (100 GR, 100 GS), which are imaged every week to observe changes in the spectral curves as the plant ages. In preprocessing, the spectral curves are normalized to remove lighting artifacts caused by height variation in the plants. A subset of hyperspectral bands is chosen using a forward selection algorithm to optimize Bhattacharyya distance between GR and GS. Dimensionality is reduced using Linear Discriminant Analysis. Maximum likelihood classification is used for plant differentiation. Previous research conducted by the authors has shown that GS and GR Palmer Amaranth (Amaranthus palmeri) can be differentiated using maximum likelihood classifiers with high accuracy (90%) with data from plants the same age. We expect to see a similar result when the Italian ryegrass plants are the same age, but when the ages are different, classification accuracy should degrade due to less Gaussian conformity in the data. If this pattern is observed, it will mean algorithms that assume Gaussian distribution may not be suitable for classifying GR and GS.

9108-25, Session 3

Bidirectional reflectance distribution function features on different wheat geometry varieties

Wenjiang Huang, Juan Zhao, Institute of Remote Sensing and Digital Earth (China); Juhua Luo, Nanjing Institute of Geography and Limnology (China)

Wheat geometry structure induces variations in spatial distribution of the canopy and problems in the inversion process of biophysical and biochemical variables. As a function of wavelength, illumination-viewing geometries and canopy structure, canopy bidirectional reflectance can characterize canopy anisotropy feature theoretically. In order to demonstrate the above theory this study explored Bidirectional Reflectance Distribution Function (BRDF) features of erective variety Jing411 and loose variety Zhongyou9507 by analyzing bidirectional NDVI?inversed BRDF model parameters and six BRDF shape indictors in red band(680nm)and NIR band(800nm) based on the semi-empirical BRDF kernel driven model. The results showed the NDVI of both erective and loose variety show explicit anisotropy and the bidirectional reflectance of two varieties behaves differently in two bands which are mainly ascribed to spatial distribution of wheat canopy, wavelengths, and illumination-viewing geometries and observing noise. Finally it is concluded wheat canopy in red band exhibits stronger surface scattering that is geometric effect and in NIR band shows stronger volumetric scattering that is volumetric effect. Therefore multi-angle observations are feasible and applicable enough to characterize wheat canopy anisotropic features.

9108-17, Session 4

High-throughput Raman chemical imaging for evaluating food safety and quality

Jianwei Qin, Kuanglin Chao, Moon S. Kim, Agricultural Research Service (United States)

A line-scan hyperspectral system was developed to fulfill macro-scale Raman chemical imaging for food safety and quality research, which generally cannot be achieved by commercial Raman imaging instruments due to their relatively small spatial coverage. The system utilizes a custom-designed 785 nm line laser to generate a 24 cm long excitation line, which is normally incident on the sample surface. Raman signals along the laser line are collected by a detection module consisting of a lens, a dispersive Raman imaging spectrograph, and a CCD camera. A hypercube is accumulated line by line as a motorized positioning table moves the samples transversely through the laser line. System software was developed using LabVIEW to fulfill parameterization and data-transfer functions. Spectral and spatial calibrations were conducted to determine the ranges and the resolutions in the two domains. Example applications for evaluating food and agricultural products were presented to demonstrate the performance of the developed system. Raman chemical images were created to show identifications, spatial distributions, and morphological features of interested analytes in the tested samples. The method and system developed in this study for macro-scale Raman chemical imaging is promising to have more applications in the area of food safety and quality evaluation.

9108-26, Session 4

Detection of pathogens in food using a SERS-based assay in just a few hours

Stuart R. Farquharson, Atanu Sengupta, Chetan S. Shende, Frank E. Inscore, Real-Time Analyzers, Inc. (United States); Jay F. Sperry, The Univ. of Rhode Island (United States)

In 2011 Escherichia, Listeria, and Salmonella species infected over 10 million people in the United States, resulting in over 50,000 hospitalizations and 1,300 deaths. In January 2013 President Obama signed into law the Food and Drug Administration (FDA) Food Safety Modernization Act (FSMA), which requires constant microbial testing of food processing equipment and food to minimize contamination and distribution of food tainted with pathogens. The challenge to preventing distribution and consumption of contaminated foods lies in the fact that just a few bacterial cells can rapidly multiply to millions, reaching infectious doses within a few days. Unfortunately, current methods used to detect these few cells rely on similar growth steps to multiply the cells to the point of detection, which also takes a few days. Consequently, there is a critical need for an analyzer that can rapidly extract and detect foodborne pathogens at 1000 colony forming units per gram of food in 1-2 hours (not days), and with a specificity that differentiates from indigenous microflora, so that false alarms are eliminated. In an effort to meet this need, we have been developing an assay that extracts such pathogens from food, selectively binds these pathogens, and produces surface-enhanced Raman spectra (SERS) when read by a Raman analyzer. Here we present SERS measurements of these pathogens in actual food samples using this assay.

9108-30, Session 4

Temperature-dependent Raman spectroscopy

Walter F. Schmidt, Moon S. Kim, Kuanglin Chao, Jianwei Qin, Hoyoung Lee, Julie K. Nguyen, Agricultural Research Service (United States)

No Abstract Available

9108-32, Session 4

Raman and NIR imaging for food adulterant detection

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No Abstract Available

9109-1, Session 2

Multi-static passive SAR imaging based on Bayesian compressive sensing

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In recent years, passive radar systems, which utilize broadcast and navigation signals as sources of opportunity, have attracted significant interests due to their low cost, covertness, and availability of rich illuminator sources. In this paper, we propose a novel method for synthetic aperture imaging in passive radar systems based on the modified Bayesian compressive sensing (BCS) technique. The problem of imaging sparse targets is formulated as a sparse signal reconstruction problem based on an L1-norm optimization, which is solved using a modified BCS method to achieve a high resolution. The proposed method significantly improves the imaging resolution beyond the range resolution. Compared to the other sparse signal reconstruction methods, such as the orthogonal matching pursuit (OMP) and Lasso, the modified BCS provides significant performance improvement for the reconstruction of sparse targets in the redundant dictionary with high coherence and is more robust to noise. Simulations results demonstrate the superior performance of the proposed method.

9109-2, Session 2

Multi-target compressive laser ranging

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Compressive laser ranging (CLR) is a method that exploits the sparsity available in the range domain using compressive sensing methods to directly obtain range domain information. Conventional ranging methods are marred by requirements of high bandwidth analog detection which includes the severe SNR fall off with bandwidth in analog-to-digital conversion (ADC). Compressive laser ranging solves this problem by obtaining sub-centimeter resolution while using low bandwidth detection. High rate digital pulse pattern generators and off the shelf photonic devices are used to modulate the transmitted and received light from a superluminescent diode source. CLR detection is demonstrated using low bandwidth, high dynamic range detectors and using photon counting techniques. The use of an incoherent source eliminates speckle issues and enables simplified CLR methods to get multi-target range profiles with a 3 cm resolution (5 GHz bandwidth) over a 6 m range window. With compressive sensing methods, 30 measurements are used to reconstruct a scene with 180 range bins demonstrating that the CLR method allows direct range measurements in the sub-Nyquist regime while reducing system resources, in particular the need for high bandwidth ADC.

9109-3, Session 2

Sparsity-based ranging for dual-frequency radars

Khodour Al Kadry, Moeness G. Amin, Fauzia Ahmad, Villanova Univ. (United States)

Dual-frequency radars offer the benefit of reduced complexity, fast computation time, and real-time target tracking in through-the-wall and urban sensing applications. Compared to single-frequency (Doppler) radar, the use of an additional frequency increases the maximum unambiguous range of dual-frequency radars to acceptable values for indoor target range estimation. Conventional dual-frequency technique uses phase comparison of the transmitted and received continuous-wave signals to provide an estimate of the target range. However, the dual-frequency approach for range estimation can be compromised due to the presence of noise and multipath. In the paper, we provide a sparsity-based ranging approach as an alternative to the phase difference based technique for dual-frequency measurements. Computer simulations are provided that illustrate the superior performance of the sparsity-based ranging technique over the conventional method.

9109-4, Session 2

Experimental results concerning compressive noise radar

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Noise radar, which refers to systems transmitting random noise-like waveforms for radar imaging have been shown to be suitable for compressive sensing. In the past, researchers have relied on theoretical results and numerical simulations to support this assertion. In real systems, one often encounters deviations from idealized theoretical models due to the effects of the devices and acquisition systems. The question of how well compressive noise radar imaging works in real systems remains open. The important issue of characterizing the performance of practical compressive noise radar imaging is addressed in this paper by analyzing results of experiments conducted with millimeter-wave and S-band radar systems. It is seen that experimental results conform closely to theoretical guarantees and numerical simulations. The experiments also help us characterize the effect of common non-idealities such as the non-ideality of the spectra and probability distributions of waveforms, on the recovery performance of compressive noise radar imaging systems. The results suggest that compressive noise radar imaging is a viable technology in practice. Further, given the low cost and simplicity of noise radar systems, the benefits of compressive sensing can be realized with few modifications to legacy noise radar systems.

9109-5, Session 2

Through-the-wall imaging using CS-MIMO radars

Yao Yu, Rutgers, The State Univ. of New Jersey (United States); Fauzia Ahmad, Villanova Univ. (United States); Athina P. Petropulu, Rutgers, The State Univ. of New Jersey (United States); Moeness G. Amin, Villanova Univ. (United States)

Through-the-wall radars (TWRs) are indispensable for situational awareness in a wide range of civilian and military applications. Multi-input multi-output (MIMO) TWR

enjoys spatial diversity, thus achieving better target detection performance in indoor environments. MIMO TWR combined with compressive sensing (CS) permits target estimation with a reduced number of samples, thereby leading to a reduction in the data acquisition time. In previous CS based MIMO approaches, the TWR transmitters were used in a time-division access fashion, which allowed the same waveform to be employed for all transmitters. In this paper, we present a CS-MIMO TWR approach, in which the transmitters emit different waveforms simultaneously, thus allowing for further reduction of acquisition time. Supporting simulation and experimental results are provided.

9109-6, Session 3

Asynchronous sampling and reconstruction of analog sparse signals

Azime Can-Cimino, Ervin Sejdic, Luis F. Chaparro, Univ. of Pittsburgh (United States)

Analog sparse signals resulting from biomedical and sensing network applications can be considered non--stationary with frequency--varying spectra. By ignoring that the maximum frequency of their spectra is changing with time sampling sparse signals unnecessarily collects samples in quiescent segments of the signal. A more appropriate sampling approach would be signal--dependent. Moreover, in many of these applications power consumption and analog processing are issues of great importance that need to be considered. In this paper we present a signal dependent non--uniform sampler that uses an Asynchronous Sigma Modulator (ASDM) which consumes low--power given its structure. By making the process depend on the derivative of the signal, we obtain a non--uniform sampler that allows the recovery of the sample values recursively. Using a Prolate Spheroidal Wave Function (PSWF) interpolation the original signal is reconstructed. Stable solutions are obtained by using baseband and modulated PSWFs function in a Tikhonov regularized interpolation. The advantage of the proposed asynchronous sampler is that range of frequencies of the sparse signal is taken into account avoiding aliasing. Moreover, that it requires saving only the zero--crossing times or their differences, and that the reconstruction can be done using their quantized values and a PSWF--based interpolation. The range of frequencies analyzed can be changed and the sampler can be implemented as a bank of filters for unknown range of frequencies. Theoretical results are illustrated with synthetic and phonocardiograph recordings of a heart sound containing the opening snap.

9109-7, Session 3

Multiple-window sparse reconstruction of FM signals from random observations

Moeness G. Amin, Yimin D. Zhang, Branka Jokanovic, Villanova Univ. (United States)

Motivated by multiple window spectrograms for enhanced time-frequency distributions of nonstationary signals, we apply multiple windows of sparse reconstructions of FM signals from random observations. The combinations of different spectrograms, corresponding to different windows, outperform each spectrogram when considered alone. With random observations, the nominal local frequency signature, common to all windows, can be extracted using multiple measurement vector sparse reconstruction techniques. The multiple observation vectors include weighted data and the corresponding sparse local frequencies have common support. The linear model, relating the measurements matrix to sparse matrix with zero and no-zero rows, has one Fourier basis dictionary. The windows can be chosen to satisfy desirable properties when spectrograms of full data observations are formed. These properties include fast computations, reduced interference, localizations, and maximizing information. In this paper, we consider windows of low-pass filter characteristics. We compare the reconstruction performance of different sets of employed windows and show improved time-frequency signature reconstruction using multiple windows compared to single window reconstruction.

9109-8, Session 3

Noise SAR image reconstruction based on compressed sensing

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In this paper, a denoise approach is proposed to reduce the speckle noise in SAR images based on compress sensing. Through the skill of compressed sensing, we divide the image into some blocks, and propose an image reconstruction method based on block compressing sensing with Orthogonal Matching Pursuit. By adding some simulated speckle noise in the SAR image, the performance of the proposed approach is shown and compared with a conventional algorithm. the result has been shown that our method can get better result in terms of peak signal noise ratio (PSNR).

9109-9, Session 3

Compressive sensing of direct sequence spread spectrum signals

Feng Liu, Michael W. Marcellin, The Univ. of Arizona (United States); Nathan A. Goodman, The Univ. of Oklahoma (United States); Ali Bilgin, The Univ. of Arizona (United States)

In this paper, compressive sensing strategies for Direct Sequence Spread Spectrum (DSSS) signals are introduced. DSSS signals avoid interception by spreading the spectrum of the original signal into a much larger bandwidth by modulating the signal with a Pseudo-Noise (PN) Sequence. PN sequences used in modulation are known to cooperative receivers. However, capturing the transmitted information is difficult for a non-cooperative receiver which does not know the PN sequence. Furthermore, the modulated spectrum covers a large frequency range and capturing this large bandwidth requires using conventional analog-to-digital converters (ADCs) at Nyquist sampling rates can become prohibitively expensive. In 2012, Liu et al. introduced compressive sensing approaches for Frequency-hopping Spread Spectrum (FHSS) signals. Motivated by this work, we develop compressive sensing approaches for DSSS signals in this work.
In our proposed system, the input DSSS signals are mixed with wideband measurement kernels and sampled at rates much lower than the Nyquist rate. A compressive matched filtering method that operates directly on the undersampled measurements is proposed to recover the transmitted bits. Strategies for designing measurement kernels beyond random kernels are also proposed. Finally, the proposed methods are evaluated using DSSS signals generated using Maximum-length sequences (m-sequences) and Phase-Shift-Keying (PSK) modulation at varying signal-to noise and compression ratios.

9109-10, Session 3

Time-frequency kernel design for compressive sensing

Branka Jokanovic, Moeness G. Amin, Yimin D. Zhang, Villanova Univ. (United States)

The Fourier transform (FT) relationship between the Wigner distributions and ambiguity function gives rise to a linear model relating the signal power distributions in both domains. The same is true for Cohen's class of time-frequency distributions where the FT maps the weighted ambiguity function to reduced interference distributions with highly attenuated cross-terms. The latter are produced by the bilinear data products underlying quadratic distribution. The time-frequency signatures for a large class of nonstationary signals, such as FM, occupy few time-frequency points, whereas the large remaining regions of the time-frequency domain assume small or zero values. This sparsity property enables sparse reconstruction of these signatures from few ambiguity domain observations. In this paper, we consider the problem of auto-terms preservations and cross-terms suppressions under the auspices of sparse signal reconstruction and compressive sensing. Rather than selecting the ambiguity domain observations manually to avoid cross-terms, we design a kernel which both reduces cross-terms and leads to sparse signal representation. The kernel considered is defined by few variables which are tuned to satisfy both objectives. We deal with both cases of full data record and records of randomly missing samples.

9109-11, Session 3

Using computer algebra to perform image compression with wavelet transform and SVD

Felipe Diaz Jaramillo, Univ. EAFIT (Colombia)

Computer Algebra Software, especially Maple and its ImageTools package, is used to develop image compression using Wavelet transform application

and Singular Value Decomposition (SVD). For prototyping of the image compression process, Maple packages, LinearAlgebra, ArrayTools and DiscreteTransform are used simultaneously with ImageTools image processing package. The image compression process implies the realization of matrix computing with high dimension matrices, and Maple software develops those operations easily and efficiently. Some image compression experiments are done, and the matrix dimension for minimum information needed to store an image is shown clearly, also the matrix dimension of redundant information. Implementation of algorithms for image compression in other computer algebra systems such as Mathematica and Maxima is proposed as future investigation path. Also it is proposed the use of curvelet transform as a tool for image compression.

9109-12, Session 4

Compressive spectral polarization imaging

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We present a compressive spectral polarization imager as the combination of a coded aperture snapshot spectral imager (CASSI) and a micropolarizer array. The proposed imaging system avoids moving or rotating optical elements and achieves real-time measurements. The CASSI imager contains a binary coded aperture and a prism which shears the scene along one spatial axis according to its wavelength components. With 0 degree, 45 degree and 90 degree linear micropolarizers randomly distributed, the micropolarizer array matched to the detector pixels intrinsically senses the first three Stokes parameters of the scene. The four dimensional (4D) data cube is thus projected onto the two dimensional (2D) focal plane array (FPA). Multiple snapshots are obtained for scenes with detailed spatial and spectral content. The 4D spectral-polarization data cube is reconstructed from the 2D measurements via nonlinear optimization with sparsity constraints. Polarization state planes (degree of linear polarization and angle of polarization) for each spectral slice of the hypercube are presented.

9109-13, Session 4

3D imaging using compressive sensing active serial imaging system

Bing Ouyang, Frank M. Caimi, Fraser R. Dalgleish, Gero Nootz, Walter Britton, Anni K. Vuorenkoski, Harbor Branch Oceanographic Institute (United States)

Compressive Sensing (CS) based active serial imaging (CSASI) concept has been developed to effectively acquire the scene intensity images in the scattering medium. The feasibility of the technique has been demonstrated via simulations and initial test tank experiments. Within this study, one of the two CSASI configurations – compressive line sensing system that adopts the whiskbroom imaging formation, more compatible with the traditional survey platforms, is further extended to recover the 3D scene. Even though the same distributed compressive sensing (DCS) theoretical foundation exploiting the both the intra-signal sparsity and highly correlated nature of the adjacent areas in a natural scene is still valid, one significant difference is that instead of a 1D spatial pattern, the measurement matrix is now a more sophisticated temporal-spatial pattern integrating the spatial pattern with modulated pulse. While the scattering mitigation techniques adopted in CSASI intensity imaging system (i.e., multi-scaled measurement matrix, model assisted reconstruction etc.) are still valid, the complications (and advantages) due to the introduction of the temporal dimension are investigated. The sensing model is developed. The impact of other system parameters such as platform motion, receiver noise is also studied. Notwithstanding the main focus so far has been image acquisition in turbid ocean water; this concept will be extended to acquire images through atmospheric scattering and attenuation (i.e., fog, mist etc.). The implementation on different imaging system configurations, especially the distributed imaging system with illuminator and receiver on different platforms is also investigated. Simulation and initial experimental results are presented as part of this work.

9109-14, Session 4

A comparison between three compressive hyperspectral sensing methods

Adrian Stern, Yitzhak August, Vladimir Farber, Yaniv Oiknine, Ben-Gurion Univ. of the Negev (Israel)

In this paper we overview some hyperspectral compressive imaging methods that we have developed. The first method is an extension of a Radon-based compressive imaging technique to perform spectral sensing [1,2]. The second method is en efficient extension of the single-pixel camera to include compressive spectrometry [3]. The third method is based on a recently developed compressive spectrometry using liquid crystal devices [4]

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9109-15, Session 4

A panchromatic super-resolution camera for remote sensing

Justin C. Flake, Booz Allen Hamilton Inc. (United States); John Greer, National Geospatial-Intelligence Agency (United States); Gary Euliss, The MITRE Corp. (United States); Stephanie Shubert, National Geospatial-Intelligence Agency (United States)

We present experiment results for a super-resolution imaging device that measures projections onto a random basis. The imaging system follows an architecture that has become familiar in compressed sensing. It uses a digital micromirror array located at an intermediate image plane to introduce binary matrices representing members of the basis set. We developed the system model from experimentally acquired calibration data which attempts to characterize the system output corresponding to each individual mirror in the array. We reconstruct images at a resolution limited by that of the micromirror array using the Split-Bregman approach to solving L1 regularized optimization problems. We evaluate system performance as a function of the size of the basis set, or equivalently, the number of projections applied in the reconstruction. Simulations show sensitivity of the approach to fundamental physical parameters certain to be encountered with real systems, including optical diffraction and noise.

9109-16, Session 4

Some results on adaptive sensing using partial-complete Hadamard waveforms

Matthew A. Herman, InView Technology Corp. (United States)

We present new results on observing a scene of interest using Partial-Complete Hadamard waveforms. The Partial-Complete schema partitions the Hadamard spectrum into separate blocks. By subsampling each of the blocks (e.g., 1%, or less) we obtain a sufficient statistic that determines the

best blocks, thereby adapting the sensing strategy to use the waveforms that are best matched to the scene. By minimizing the total variation of the reconstructed image, significant improvement is achieved as compared to simply sensing with Hadamard waveforms that are randomly chosen, i.e., those that do not use any a priori knowledge of the scene.

9109-17, Session 5

Parallel and reconfigurable architectures for OMP compressive sensing reconstruction algorithm

Amey M. Kulkarni, Tinoosh Mohsenin, Univ. of Maryland, Baltimore County (United States)

Compressive Sensing (CS) is a novel scheme, in which a signal that is sparse in a known transform domain can

be reconstructed using fewer samples. The signal reconstruction techniques are computationally intensive and power consuming, which makes them impractical for embedded applications. The paper presents novel architectures for Orthogonal Matching Pursuit algorithm, one of the popular CS reconstruction algorithms.

We show the implementation results of proposed architectures on FPGA, ASIC and on a custom many-core platform. For FPGA and ASIC implementation, a novel thresholding method is used to reduce the processing time by at least 25%. Whereas, for the programmable custom manycore platform, efficient parallelization techniques are applied, to reconstruct signals with variant signal lengths of N and sparsity of m. The algorithm is divided into three kernels. Each kernel is parallelized to reduce execution time, whereas efficient reuse of the matrix operators allows us to reduce area. Matrix operations are efficiently paralellized by taking advantage of blocked algorithms. For demonstration purpose, all architectures reconstruct a 256-length signal with maximum sparsity of 8 using 64 measurements. Implementation on Xilinx Virtex-5 FPGA, requires 27.14µs to reconstruct the signal using basic OMP. Whereas, with thresholding method it requires 18 µs. ASIC implementation reconstructs the signal in 13 µs and our custom many-core, operating at 1.18 GHz, takes 18.28 µs to complete. Our results show that compared to the previous published work of the same algorithm and matrix size, proposed architectures for OMP are approximately 1.3 times to 3 orders of magnitude times faster.

9109-18, Session 5

A photonics hardware based wideband compressive sensing analog to digital architecture and signal recovery method

Mohiuddin Ahmed, HRL Labs., LLC (United States)

We present a compressed sensing (CS) approach for the sub-Nyquist, non-uniform sampling (NUS) and reconstruction of wideband RF-signals. The random sampling is accomplished via nonuniform time-stretching in a photonic time-stretch (TS) ADC system that has been developed as part of the DARPA RADER program.

We previously reported the photonic TS ADC system that utilizes voltage-tunable dispersive elements capable of large stretch-ratio M~41 to accomplish randomized sampling of a time-stretched analog-input modulated onto a chirped optical carrier (we demonstrated an effective number of bits (ENOB)> 8 for an input signal frequency of 10 GHz). However, while using a large stretch ratio (M) was key to our demonstration of a high ENOB, a TS ADC system constructed with a stretch ratio of 41 would require a large number of parallel channels to accomplish continuous time (CT) operation.

In this paper, we explore a novel CS-based approach utilizing nonuniform randomized subsampling that will enable us to reduce the time-stretch ratio M because the same backend ADC bank can cover (i.e., "sense") a wider signal spectrum, with minimal tradeoff in ENOB. Furthermore we discuss the resulting CS formalism for reconstructing the input-signal from measured data collected via nonuniform sampling. Using the matrix formalism, it is seen that well known CS algorithms such as L1 or Orthogonal Matching Pursuit (OMP) can be employed to recover the input estimates from the measured output of the ADC subsystem.

9109-20, Session 5

Direction finding with L1-norm subspaces

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Conventional subspace-based signal direction-of-arrival estimation methods rely on the familiar L2-norm-derived principal components (singular vectors) of the observed sensor-array data matrix. In this paper, for the first time in the literature, we find the L1- norm maximum projection components of the observed data and search in their subspace for signal presence. We demonstrate that L1-subspace direction-of-arrival estimation exhibits (i) similar performance to L2 (usual singular-value/eigen-vector decomposition) direction-of-arrival estimation under normal nominal-data system operation and (ii) significant resistance to sporadic/occasional directional jamming and/or faulty measurements.

9109-21, Session 5

Tomographic reconstruction of an unstable flame with compressive sensing and double ART algorithm: a comparison

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Two classical approaches to recover the temperatures distribution in a flame are the Radial Abel Inversion and the Filtered Back Projection. The first one is useful when the flame is considered as an object with cylindrical symmetry and the second one is useful when the flame has not a particular symmetry and the number of projections is high. In the case of having only few projections, an algebraic reconstruction tomography (ART) algorithm can be used. In this work, we use compressive sensing for recovering the temperatures distribution in an unstable flame, using four projections and shown its performance comparing it with an improved ART version, which is called the Double Art Algorithm. Experimental results and reconstruction of temperatures distribution are obtained with both approaches and shown.

9109-39, Session 5

Groundwater monitoring using sparse recovery algorithm

Joon Young Lee, Tae-Woo Lee, Arizona State Univ. (United States)

Groundwater level estimation has been investigated in the southwestern United States for a long time period. In this study, we introduce compressed sensing and apply it to the groundwater level estimation. First, we describe that compressed sensing is applicable to the groundwater level estimation. Relying on the US Geological Survey and the State Department of Water Resources for important data, we show in steps how to build the groundwater level network data. The mathematical formulation is shown and the L1-optimization is formulated for the proposed method. By several validity tests, we show that it meets the compressible requirements and L1-optimization enables groundwater level estimation to be effective in that the total measurements of registered wells can be reduced down by approximately 42%. We provide visualizations of groundwater level estimation in the southwestern US and trends of groundwater level change in cities of Arizona from 1942 to 2012.

9109-22, Session 6

Compressive sensing optical coherence tomography using randomly accessible tunable lasers

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We propose and demonstrate a novel a compressive sensing swept source optical coherence tomography (SSOCT) system that enables high speed images to be taken while maintaining the high resolution offered by a large bandwidth sweep.

Conventional SSOCT systems sweep the optical frequency of a laser to characterize the interference pattern at a given lateral location. A scatterer located at delay T appears as a sinusoidal component cos (w(t)T) at the photodetector current. Limitations imposed by the finite optical chirp rate, the speed of analog to digital and digital to analog converters, limit the acquisition rate of an axial scan. The proposed acquisition modality enables much faster image acquisition rates by interrogating the beat signal at randomly selected optical frequencies while preserving resolution and depth of field.

The system utilizes a randomly accessible laser, a modulated grating-Y branch laser, to sample the interference pattern from a scene at randomly selected optical frequencies over an optical bandwidth of 5 THz , corresponding to a resolution of 30 um in air. The depth profile is then reconstructed using l1 recovery algorithm with a LASSO constraint. Signal dependent noise sources, shot noise and phase noise, are analyzed and taken into consideration during the recovery. Redundant dictionaries are used to improve the reconstruction of the depth profile. A compression by a factor of 10, for sparse targets, up to a depth of 15 mm in noisy environments is shown.

9109-23, Session 6

Understanding differences between healthy swallows and penetration-aspiration via compressive sensing of tri-axial swallowing accelerometry signals

Ervin Sejdic, Joshua M. Dudik, Iva Jestrovic, Atsuko Kurosu, James L. Coyle, Univ. of Pittsburgh (United States)

Swallowing is a well-defined process of transporting food or liquid from the mouth to the stomach [1]. Patients suffering from dysphagia (swallowing difficulty), usually deviate from this well-defined pattern of healthy swallowing. Dysphagia is a common problem encountered in the rehabilitation of stroke patients, head injured patients, and others with paralyzing neurological diseases [2]. Patients suffering from dysphagia are prone to choking or penetration/aspiration. Aspiration is defined as process when any food or fluids enter into the airway below the true vocal folds [1]. A related phenomenon to aspiration, penetration is defined as the event when material enters the space immediately above the true vocal folds (the supraglottic space) but is not observed to fall below the vocal folds during assessment [2].

In recent years, swallowing accelerometry became a promising non-invasive tool for the assessment of swallowing difficulties, including penetration-aspiration. Swallowing accelerometry refers to the employment of an accelerometer as a sensor modality during cervical auscultation. A recent contribution showed that penetration-aspiration swallows have different time-frequency structures from healthy swallows [3]. In this paper, we propose to examine whether the differences in the time-frequency structure of swallowing accelerometry signals will play a significant role in acquiring such signals using compressive sensing. In particular, we will examine the compressive sensing approach based on modulated discrete prolate spheroidal sequences [4].

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9109-24, Session 6

Highly accelerated 3D dynamic contrast enhanced MRI from sparse spiral sampling using integrated partial separability model and JSENSE

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Dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) has been used clinically to provide a collection of sequential sets of morphological images. These MRI "movies" represent a potentially major development in the management of a wide range of diseases and have particular applicability in oncology. It requires high spatial resolution for morphological information and high temporal resolution for contrast pharmacokinetics. In the existing DCE-MRI methods, the spatial resolution has to be compromised for the required temporal resolution. Its practical impact is still limited by the relatively low spatiotemporal resolution.

A number of methods have been proposed to improve the spatiotemporal resolution of dynamic imaging by highly undersampling the MRI data in (k,t) space and reconstructing the image using spatial, temporal or both constraints. When combined with other fast imaging techniques, such as fast scanning and parallel imaging, these methods hold promise for even higher spatiotemporal resolution. Some recent works have investigated compressed sensing for fast dynamic imaging.

In this paper, we propose a novel method to effectively integrate spiral acquisition, parallel imaging, partial separable (PS) model, and sparse constraints for highly accelerated dynamic contrast enhanced MRI. In data acquisition, the proposed method exploits 3D spiral trajectories with golden angle. In image reconstruction, the coil sensitivities, spatial and temporal bases of the PS model are jointly estimated through alternating optimization. The experimental results show that the proposed method is able to achieve high spatial and temporal resolutions at the same time.

9109-25, Session 6

Graphics processing units accelerated MIMO tomographic image reconstruction using target sparseness

Yuanwei Jin, Univ. of Maryland Eastern Shore (United States); Pedro Bello-Maldonado, Florida International Univ. (United States); Agustin Rivera-Longoria, Texas State Univ. San Marcos (United States); Mark Idleman, Ahmerst College (United States); Enyue Lu, Salisbury Univ. (United States)

With progress in imaging systems and algorithms, the computational complexity of image reconstruction has increased dramatically. Wave based

nonlinear imaging such as tomography for medical applications typically employs iterative reconstruction approaches, which are computationally challenging due to the increased sophistication of imaging algorithms and the amount of data processed. Processing time is now limiting the deployment of advanced imaging technologies. To address this challenge, two approaches have been taken. The first approach is to develop new algorithms that incorporate prior knowledge such as target sparseness to accelerate image reconstruction. The second approach is to employ powerful hardware to address computational aspects of real-time image reconstruction. The graphics processing unit (GPU) has emerged as a competitive platform for computing massively parallel problems.

In this paper, we develop integrated approaches to accelerating nonlinear tomographic image reconstruction. First, we study new imaging algorithms for non-linear tomographic image reconstruction using target sparseness. The iterative algorithm consists of the propagation step and the backpropagation step under which the target characteristic function values are updated and reconstructed. Using numerical examples, we demonstrate that incorporating prior knowledge about the imaging field such as target sparseness accelerates significantly the convergence of the iterative imaging method, which provides considerable benefits to real time tomographic imaging applications. Next, we develop efficient implementation strategies and methods using Graphics Processing Units to further reduce processing time of the tomographic imaging algorithm. By exploiting the underlying parallelism of the iterative image algorithm, we test different Compute Unified Device Architecture (CUDA) kernel configurations offered by GPU in order to measure the changes in the processing time of our algorithm. By examining the imaging speed and the resulting image quality, optimal kernel configurations are developed to maximize the throughput of the CUDA implementation for the iterative imaging method. The implementation results demonstrate that a combined approach, i.e., algorithm development and GPU implementation, yields significant improvement for the iterative method in terms of processing time and image quality.

9109-26, Session 6

Multimodal sparse reconstruction in Lamb wave-based nondestructive evaluation

Andrew Golato, Sridhar Santhanam, Fauzia Ahmad, Moeness G. Amin, Villanova Univ. (United States)

Lamb waves are utilized extensively for nondestructive evaluation (NDE) of thin structures, such as plates and shells. These guided ultrasonic waves can travel long distances without significant attenuation and interact with defects, thereby permitting quick examination of broad areas in structural health monitoring and NDE applications. Normal practice involves fixing a network of piezoelectric transducers to the structural plate member for generating and receiving Lamb waves. Using the transducers in pitch-catch pairs, the scattered signals from defects in the plate can be recorded. While several techniques exist for analyzing the scattered signals to detect the presence of defects, very few exploit the sparseness of scattering sources or defects in the plate.

In this paper, we propose an L1-norm minimization approach for localizing defects in thin plates, which inverts a multi-modal Lamb wave based model through exploitation of group sparsity. More specifically, we assume the defects to be isotropic scatterers and consider both symmetric and asymmetric fundamental propagating Lamb modes. We construct model-based dictionaries for each mode, taking into account the associated dispersion and attenuation through the medium. Reconstruction of the area being interrogated is then performed jointly across the two modes using the group sparsity constraint. Performance validation of the proposed defect localization scheme is provided using both simulated data and experimental data gathered from an aluminum plate, with damage in the form of holes and added masses, at the Acoustics and Ultrasound Lab, Villanova University.

9109-27, Session 7

A new class of masks and algorithms for efficient coded aperture imaging and decoding

Michael J. DeWeert, BAE Systems (United States)

In certain applications, such as X-ray astronomical imaging, conventional lens technology is constrained by the lack of materials which can effectively focus the radiation within reasonable weight and volume. One solution is to replace lenses with coded apertures –opaque plates perforated with multiple pinhole-like apertures which create an overlapping jumble of images on the image plane of the camera. If the apertures are arranged in an appropriate pattern, the images can be decoded, and a clear image computed. Recently, interest in computational imaging and the search for means of producing programmable software-specified optics has revived interest in coded apertures. MURA (Modified Uniformly Redundant Array) masks have long been the state of the art for coded-aperture imaging. While MURAs work well for compact objects against uniform backgrounds, they have several drawbacks for extended scenes: 1) they present an inherently ill-posed inversion problem that is unmanageable for large images, and 2) they are susceptible to diffraction effects: a diffracted MURA is no longer a MURA. This talk presents a new class of coded apertures which are efficiently decodable, even for very large images –orders of magnitude faster than MURAs. The new mask class also remains decodable when diffracted. We present the theory and experimental confirmations of the effectiveness of the new method - images collected in natural light of extended outdoor scenes are rendered clearly. We also demonstrate software-defined optics using programmable Spatial-Light-Modulators. The new class of masks is potentially a game-changed for future developments of efficient X-ray and gamma-ray imagers.

9109-28, Session 7

Rate-distortion optimization for compressive video sampling

Ying Liu, Joohee Kim, Illinois Institute of Technology (United States)

The recently introduced compressed sensing (CS) framework enables low complexity video acquisition via sub-Nyquist rate sampling. In practice, the resulting CS samples are quantized and indexed by finitely many bits (bit-depth) for transmission. In applications where the bit-budget for video transmission is constrained, a tradeoff exists between number of collected CS samples and quantization bit-depth per CS sample. In this work, we establish a video content-adaptive quantization scheme which maximizes the reconstruction quality in a bit-budget constrained CS video transmission system. In particular, the reconstruction peak-signal-to-noise ratio (PSNR) is modeled as a quadratic function of quantization bit-depth with model parameters adaptive to signal sparsity. The optimal bit-depth is obtained by setting the first derivative of the function to zero. In the experimental studies the model parameters are initialized with a small set of training data, which are then updated with local information in the model testing stage. Simulation results presented herein show that the proposed adaptive quantization scheme outperforms significantly fixed bit-depth quantization.

9109-29, Session 7

Image estimation from projective measurements using low dimensional manifolds

Johann Veras, Robert R. Muise, Lockheed Martin Corp. (United States)

We look at the design of projective measurements based upon image priors. If one assumes that image patches from natural imagery can be modeled as a low rank manifold, we develop an optimality criterion for a measurement matrix based upon separating the canonical elements of the manifold prior. Any sparse image reconstruction algorithm has improved performance

using the developed measurement matrix over using random projections. Some insights into the empirical estimation of the image patch manifold are developed and several results are presented.

9109-30, Session 7

A fast target detection and imaging method for compressive sensing Earth observation

Chuanrong Li, Academy of Opto-Electronics (China); Qi Wang, Academy of Opto-Electronics (China) and Univ. of Chinese Academy of Sciences (China); Changyong Cao, NOAA National Environmental Satellite, Data, and Information Service (United States); Xi Shao, Univ. of Maryland, College Park (United States); Lingling Ma, Yongsheng Zhou, Academy of Opto-Electronics (China); Shi Qiu, Univ. of Maryland, College Park (United States); Jianjian Li, Academy of Opto-Electronics (China) and Univ. of Chinese Academy of Sciences (China) and NOAA National Environmental Satellite, Data, and Information Service (United States)

The compressive sensing imaging technique, based on the realization of measurement matrix via active or passive devices (e.g., DMD), has attracted more and more attention. For imaging target of interest within large sparse scene (e.g., ships in the sea), high-resolution image was usually reconstructed, however the process is time-consuming, and moreover only part of the image consists of the targets of interest. In this paper, the non-imaging fast target detection was realized first based on the detector energy intensity, which includes the steps of rough target positioning by successively opening DMD blocks and accurate positioning by adjusting the rough areas via intelligent search algorithm. Further, multi-resolution fast imaging method via combining different numbers of DMD mirrors was explored, low resolution for larger area and high resolution for smaller area containing the targets. Simulation experiments were carried out to compare the proposed method with regular method. The calculation time is 2.93 seconds for the proposed method and 44.9 seconds for reconstructing image of the whole scene in low resolution. The result shows the area of the ships are accurately positioned without reconstructing the image by the proposed method and the multi-level scale imaging for suspect areas is realized. Compared with traditional method from the reconstructed image, the proposed method highly enhances the measuring and reconstruction efficiency for ships in the ocean.

9109-31, Session 7

A new approach to apply compressive sensing to lidar sensing

Richard C. Lau, T. K. Woodward, Applied Communication Sciences (United States)

In recent years, Compressive Sensing (CS) has been successfully applied to multiple branches of science. However, most CS methods require capturing a large amount of random projections of the data sequentially, which does not directly apply to LIDAR systems where reduction of sampling of 3D point cloud is desirable. In this paper, we propose a new method called Re-sampling Compressive Sensing (RCS) that relaxes the sampling of LIDAR point cloud to only once to capture 3 dimensional scenes at a given performance. The proposed new CS method leads to a new data collection paradigm that is general and is different from traditional CS sensing such as the single-pixel camera architecture.

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9110-1, Session 1

Active versus passive projector nonlinear gamma compensation method for high-quality fringe pattern generation *(Invited Paper)*

Song Zhang, Iowa State Univ. (United States)

Nonlinear gamma of the projector induces substantial measurement error if it is not properly compensated. Over the years, numerous projector nonlinear gamma compensation methods were proposed. Overall, these methods can be classified into two categories: actively modifying the fringe patterns before their projection, or passively compensate the phase error after the patterns are captured. Both methods have been proved successful in substantially reducing the nonlinearity error caused by the projector. However, to our knowledge, there is no study on comparing these two types of error compensation methods for high-quality fringe patterns when the system is not operating under its calibrated optimal conditions, e.g., when the projector is substantially out of focus. This paper thus presents a study examining the influences of projector defocusing on the phase quality while the projector nonlinearity is calibrated under an in-focus condition. Our study finds that the active method tends to provides more consistent high-quality fringe patterns regardless the amount of defocusing; yet the effectiveness of the passive method is sensitive to the measurement conditions, albeit the passive method could provide slightly better quality phase under the optimal calibration condition. This research finding coincides with our prior study on binary defocusing study where the phase error varies with different amounts of defocusing, and thus compensating the phase error passively in phase domain is more difficult than actively modifying the fringe patterns before their projection.

9110-2, Session 1

Accurate projector calibration based on improved accuracy of points in projector images corresponding points in camera images

Zhengrong Huang, Jiangtao Xi, Yanguang Yu, Qinghua Guo, Univ. of Wollongong (Australia)

As an important part of 3D fringe projection profilometry, projector calibration is a complicated and time-consuming procedure. As the projector cannot capture pictures directly, it is calibrated by establishing corresponding relationship between a set of points on projector images and camera images, that is, by mapping the points in camera images into the projector images. The more precise the mapping, the more accurate the calibration can be. The method of phase-shifting is used to map the extracted points in camera images into projector images, where each pixel on charge-the coupled device of camera corresponds to one pixel in the digital micro-mirror device of projector. Although the points in camera images can be located precisely, the accuracy will reduce when they are mapped onto the projector images. In this paper, we propose a new method to improve the accuracy of the mapping. The key concept is to extract a set of pixels on the edge of a circle, from which the centre of the circle can be determined by the least-square fitting. Meanwhile, the set of edge pixels are mapped onto the projector images using the approach of phase-shifting. After obtaining these edge pixels in the projector images, the least-square fitting is used again to extract the centre of the circle, thus establishing corresponding relationships between the circle centre on the camera image and projector image. Compared to existing approaches based on direct mapping of the circle centre on the camera image to the projector image, Our proposed method is characterized by higher accuracy in the mapping the points and thus the projector calibration. The principle of the improved method is described in this paper, and the effectiveness is demonstrated by the results of experiments.

9110-3, Session 1

Comparing digital-light-processing (DLP) and liquid-crystal-on-silicon (LCOS) technologies for high-quality 3D shape measurement

Chen Gong, Beiwen Li, Iowa State Univ. (United States); Kevin G. Harding, GE Global Research (United States); Song Zhang, Iowa State Univ. (United States)

This paper presents a thorough comparison between the projector using the digital-light-processing (DLP) technology and liquid-crystal-on-silicon (LCOS) technology for high-quality 3D shape measurement. Our prior study indicated that there are significant differences between these two technologies depending upon the employed fringe generation method (i.e., focused sinusoidal or binary defocusing). Namely, the DLP technology performs better using the binary defocusing technique since the resultant fringe contrast is higher; and the LCOS technologies is better when the focus sinusoidal method is used because the LCOS has less stringent timing requirement for the systems. However, our prior study was investigated on the inexpensive DLP and LCOS platforms, and only utilized one single color for comparisons, and thus such a study might not be representative since the inexpensive projectors might not take full advantage of each individual technologies. This study will utilize regular DLP and LCOS projectors and thoroughly compare their differences on high-quality 3D shape measurement. Specifically, we will not only study each individual color, we will also study the combinations of different colors. Again the binary defocusing and focused sinusoidal fringe projection methods will be evaluated under all these scenarios. Experimental data will be presented and hopefully conclusions will be drawn on choosing one of the two technologies once the fringe generation method is determined for a particular application.

9110-4, Session 1

Influence of alpha factor on the stability limit of a semiconductor laser with optical feedback

Yuanlong Fan, Yanguang Yu, Jiangtao Xi, Qinghua Guo, Univ. of Wollongong (Australia)

A single mode semiconductor laser (SL) with external optical feedback (EOF) has been being attracted an extensive attention due to its wide applications, such as optical chaos transmitters/receivers, self-mixing sensing and instrumentations for the metrological quantities of an external target. In the applications, the analysis on the stability of such SLs is desired for achieving a reliable SL application system. A constant current biased SL usually emits laser with a constant intensity under the condition of stable operation. However, with the variance of system parameters, the laser output transits into unstable behavior, such as periodic oscillation, quasi-periodic oscillation, low frequency fluctuations (LFFs) or chaos. It is important to figure out when the transition occurs with respect to the values of the parameters, or the range of the parameters within which the SL is stable or unstable. Such a range is referred to as the stability limit. To determine the stability limit, many relevant works have been conducted in the past decades. Alpha factor (also referred to as the linewidth enhancement factor or the Henry factor) is one of the fundamental parameters for SLs. It was reported that value of alpha factor is very important for describing many aspects of laser behavior, such as spectral effects, injection locking, and the chirp. However, the influence of the alpha factor on the stability limit has not been fully investigated. In this paper, starting from the L-K equations, two coupling equations for describing the stability limit of the system are derived. Based on the coupling equations, the stable region of an SL with EOF is obtained and described by alpha factor incorporating three other controllable external parameters associated with EOF. The computer simulations show the final stability limit in a

3-parameter space described by any three of the parameters, therefore providing a complete and better way for designing a stable SL system with EOF.

9110-5, Session 1

Improved measurement dynamic range for point triangulation probes

Kevin G. Harding, GE Global Research (United States); Mehdi Daneshpanah, KLA Tencor (United States); Guangping Xie, Li Tao, GE Global Research (China)

Point triangulation probes have been in use in industry for half a century. In that time, there has not been any big changes in the mechanism by which they operate A point laser triangulation gage bought today has about the same ratio of standard deviation to measurement range, or measurement dynamic range, as one bought 30+ years ago. A significant limiting factor of the measurement dynamic range of such sensors is the noise seen by the sensor, which consists of both classic speckle noise, but also just the effects of surface texture on the reflected beam. This paper will discuss three different methods, based upon advances applied in other optical metrology systems, that improve the standard deviation to measurement range ratio for point laser triangulation gage by a factor of 20 on average. We will present the theory of how each of these methods provide this improved measurement dynamic range as well as the results of laboratory tests made on breadboard systems.

9110-6, Session 2

Experimental studies of the influence on object surface characteristics on the fringe patterns

Jiangtao Xi, Yifan Wei, Yanguang Yu, Qinghua Guo, Univ. of Wollongong (Australia)

Fringe pattern profilometry(FPP) based on digital fringe projection has been widely used to measure the 3-D shape of object . The denoising of the fringe patterns is one of the key tasks to be addressed.

There are already some existing methods for denoising the fringe patterns. One widely used method is based on partial differential equations, which is flexible and has stable results.Another method is based on Windowed Fourier Filtering and an adaptive windowed Fourier filtering method enables lossless reconstructed fringe patterns. There are also some other methods with different advantages. Although all of these researches have provided the algorithms to reduce noise from fringe pattern, there is not enough work focusing on the influence of object surface characteristics on the fringe patterns.

This paper presents a comparative study which focuses on the characteristics of object with different material. In order to get comprehensive data, we do the experiment in different conditions including different backgroundlight condition and different object surface characteristics in terms of colour and reflectivity. From the experiment, we can obtain not only the characteristics of the noise resulting from different object surface material in the same light condition, but also the data of same material in different backgroundlight condition. The noise properties obtained are employed for the development of effective denoising algorithms to improve the measurement accuracy.Simulations and experiments are presented to verify the results.

9110-7, Session 2

Error correction for Moiré based creep measurement system

Yi Liao, GE Global Research (United States)

Due to the high temperatures and stresses present in the high-pressure section of a gas turbine, the airfoils experience creep or radial stretching. Nowadays manufacturers are putting in place condition-based maintenance programs in which the condition of individual components is assessed to determine their remaining lives. To accurately track this creep effect and predict the impact on part life, the ability to accurately assess creep has become an important engineering challenge. One approach for measuring creep is using moiré imaging. Using pad-print technology, a grating pattern can be directly printed on a turbine bucket, and it compares against a reference pattern built in the creep measurement system to create moiré interference pattern. The authors assembled a creep measurement prototype for this application. By measuring the frequency change of the moiré fringes, it is then possible to determine the local creep distribution. However, since the sensitivity requirement for the creep measurement is very stringent (0.1 micron), the measurement result can be easily offset due to optical system aberrations, tilts and magnification. In this paper, a mechanical specimen subjected to a tensile test to induce plastic deformation up to 4% in the gage was used to evaluate the system. The results show some offset compared to the readings from a strain gage and an extensometer. By using a new grating pattern with two subset patterns, it was possible to correct these offset errors. The experimental results show a good agreement of the moiré based strain gage with extensometer readings after correction.

9110-8, Session 2

An improved phase unwrapping method using two fringe patterns with selected frequencies

Pu Cao, Jiangtao Xi, Yanguang Yu, Qinghua Guo, Univ. of Wollongong (Australia)

Fringe pattern profilometry (FPP) based on digital fringe projection (DFP) is a promising optical noncontact three-dimension (3D) profile measurement technologies due to its accuracy and flexibility. A number of FPP approaches have been introduced. The most widely used methods are on the basis of phase difference estimation (PDE).

Phase unwrapping problem is a major problem associated with PDE-based FPP approaches. This problem arises because the phase difference can only be detected within the main value range of [-ϖ, ϖ], but the true phase difference can be arbitrary. In order to retrieve the actual surface shape of the object, a phase unwrapping method using two fringe patterns with selected frequencies was introduced by Ding. Compared to existing temporal multiple-frequency algorithms, the two frequencies in the proposed method can be high enough and thus enable efficient and accurate recovery of absolute phase maps. However, a problem existed in this method, that is, the arithmetic rounding operation has a high potential to introduce errors. Once these errors occurred, the lookup table will return with wrong values, hence introducing a great phase error in retrieved absolute phase map.

In this paper, we present an improved phase unwrapping method to solve the above mentioned problem. We will firstly present analysis on the problem existed in rounding operation and successfully retrieve the correct values using the relationship of two absolute phase maps of the two fringes. Theoretical analysis and experimental results are presented to confirm the effectiveness of the proposed technique.

9110-9, Session 3

Development of in-plane and out-of-plane deformation simultaneous measurement method by using only two speckle patterns *(Invited Paper)*

Yasuhiko Arai, Kansai Univ. (Japan)

The deformation measurement method by using only two speckle patterns has been proposed in ESPI by using Fourier transform. In this paper, a new method which can measure an in-plane and out-of-plane deformation

of the object with rough surfaces is developed for the measurement of dynamic events. The in-plane deformation can be generally detected by using the two-beams speckle interferometer. Then, the two-beams speckle interferometer has been set up by two beams and a camera. However, the roles of the beams and the camera in the measurement are discussed. The proposed optical system for the measurement of the simultaneous in-plane and out-of-plane deformation is constructed using two cameras and one beam. And, the analyzing algorithm, which can separate each component of in-plane and out-of-plane deformation, is also proposed. Speckle patterns from each camera before and after the deformation are analyzed using only two speckle patterns in order to detect the phase maps concerning the deformation of each camera. Then, the optical path differences before and after deformation are detected. Finally, the in-plane and out-of-plane deformation can be measured by using a pair of the optical path difference results based on the geometry of two cameras. From experimental results, it is confirmed that the new method can analyze a pair of in-plane and out-of-plane deformation simultaneously in a high resolution power. It is also confirmed that the resolution power of the measurement of this method is higher than 1/150 wavelength of the light source.

9110-10, Session 3

Low-coherence interferometer using a pulsation laser diode *(Invited Paper)*

Takamasa Suzuki, Yusuke Ueno, Samuel Choi, Osami Sasaki, Niigata Univ. (Japan)

In precision manufacturing, optical interferometry is commonly used to perform various types of fine measurements. However, conventional interferometer cannot be adapted to rough surfaces or step heights greater than half of the optical wavelength. White-light or low-coherence interferometry is one of the key technologies to overcome such problems. Recently, optical coherence tomography (OCT) has been attracted massive attention on biological measurements. This technology is very useful also for industrial inspections. In this paper, we propose low-coherence interferometry based on spectral domain (SD-) OCT and demonstrate two-dimensional step-height measurements. Usually, SD-OCT has certain drawbacks; for example, it requires an invisible and expensive super luminescent diode (SLD) and a mechanical scanning system for realizing full field measurements. We use a conventional laser diode (LD), which emits light with multimode oscillation, as a light source instead of the SLD. Although the spectral range of such a LD is not so wide compared with the SLD, it is visible and economical. The visible light allows easy alignment control and measurement. To overcome the second drawback, we use a cylindrical lens and acousto-optic deflector (AOD) instead of a mechanical scanning system. A linear light generated by the cylindrical lens makes it possible to conduct one-dimensional measurement. Moreover, a full field or two-dimensional measurement can be implemented with the linear light that is scanned by the AOD. Because no mechanical elements are required in our proposed system, a fast and smooth scanning can be realized in the measurement.

9110-11, Session 3

Three-dimensional imaging with multiple wavelength speckle interferometry

Bruce E. Bernacki, Bret D. Cannon, John T. Schiffern, Albert M. Mendoza, Pacific Northwest National Lab. (United States)

We present the design, modeling, construction, and results of a three-dimensional imager based upon multiple-wavelength speckle interferometry. Speckle imaging used in non-destructive evaluation is well-known but requires a precisely acquired reference image and can measure excursions only within the two-pi ambiguity range determined by the illumination wavelength. Our approach is based upon earlier efforts pioneered by Takeda but with updated illumination, imaging, and processing tools in which a surface under test is illuminated with tunable laser light in a Michelson interferometer configuration. A speckled image is acquired at each laser frequency step creating a data hypercube. Interference between the reference wavefront and light from the object causes the amplitude of the speckles to cycle with laser tuning. Fourier transforming the hypercube in the frequency dimension reveals beat frequencies that map heights of surface features. Height resolution is determined by the tuning characteristics of the laser, which for our 16-nm tuning range provides approximately 18 micron resolution without any efforts at interpolation. The largest height without wraparound depends on the smallest tuning steps, which for our laser is 15 cm for 0.002 nm (1 GHz) tuning steps. In this way, objects with large discontinuous steps or holes can be imaged without confusion. Also, due to the illumination beam being normal to the surface under test, shadowing is eliminated. To inform our design and better understand our system's limitations, we have developed extensive numerical models based upon Monte Carlo ray tracing in which speckle patterns are produced after scattering from model surfaces by coherent summing of rays at the detector plane. Data acquired by the system as well as modeling results will be shown.

9110-12, Session 3

Real-time and uniaxial measurement of 3D profile by polarization camera

Shuhei Shibata, Fumio Kobayashi, Daisuke Barada, Yukitoshi Otani, Utsunomiya Univ. (Japan)

An optical three-dimensional surface measurement has an advantage for non-contact, non-destructive and short measuring time. Many methods of three-dimensional surface measurement have been proposed. A stereo method of those is useful for many variations such as a moire and a grating projection. However these methods can't apply a deep hole or steep hight. Because intensity of bottom isn't captured with shadow portion. To overcome this problem, a method of uniaxial measurement of three-dimensional surface is introduced by polarization camera which is made pixel polarizers attached on CCD sensor. The directions of polarizer array are composed to 0°, 45°, 90° and 135°. A polarization grating is controlled in spatially using a quarter wave plate and a spatial light modulator which is projected onto a sample. Intensity reflected from sample is detected by polarization camera. A contrast of projected sinusoidal pattern onto sample is approximated the Gauss distribution along depth direction. This contrast fitting to the Gauss function is measured in advance. This method can be measured the contrast distribution in real-time by 4 stepping phase shifting technique using 4 pixels of different polarizer array. The three-dimensional coordinate is calculated relationship Gauss distribution and measuring contrast. We propose real-time and uniaxial three-dimensional surface measurement using polarization grating controlled by spatial light modulator.

9110-13, Session 3

Digital fringe profilometry based on triangular fringe patterns and spatial shift estimation

Jiangtao Xi, Pu Cao, Yanguang Yu, Qinghua Guo, Univ. of Wollongong (Australia)

In recent years, optical noncontact three-dimension (3D) profile measurement has attracted increasing research efforts due to many potential applications. Among other approaches, the fringe pattern profilometry based on digital fringe projection has been proven to be one of the most promising techniques due to the advantages of simple system structure, flexible fringe pattern generation and high accuracy.

A number of fringe pattern profilometry approaches have been introduced. The most widely used methods are on the basis of phase difference detection. However, phase difference detection approaches suffer from a number of disadvantages. A major problem is the influence of nonlinear distortions inherent to digital video projection. Such distortions make it difficult for the original fringe patterns to be either sinusoidal or

ideal periodic, which are required by phase difference detection based approaches.

In this paper, we present a new approach for the 3D measurement using digital fringe projection. Instead of sinusoidal fringe patterns and the traditional phase difference detection, the proposed technique makes use of triangular patterns and the spatial shift estimation for extract the 3D shape. The proposed technique is advantageous not only by improved immunization to nonlinear distortion associated with digital projections, but also reduced computational burden for its implementation. Theoretical analysis and experimental results are also presented to confirm the effectiveness of the proposed technique.

9110-14, Session 4

Array-projected aperiodic sinusoidal fringes for high-speed 3D shape measurement

Stefan Heist, Andreas Mann, Peter Kühmstedt, Gunther Notni, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

In recent years, the demands on three-dimensional (3D) measurement systems have been getting higher, especially concerning their speed: In case of in-line quality control or medical sciences one has to deal with fast-moving objects and/or the need of a short recording time. Due to their benefits like allowing full-field measurement and contactless operation, coded-light techniques are a well-established method for performing these measurements. However, conventional systems are limited by the projection speed which is typically in the range of a few 100 Hz.

The use of a so-called 3D array projector, as presented and suggested in previous publications, enables much higher projection frame rates of up to the 100 kHz range. In this contribution, we present a new purpose-built prototype of such a 3D array projector. In contrast to previous setups, it does not project well-known phase-shifted sinusoidal fringes and Gray code patterns, but aperiodic sinusoidal fringes. This new technique, based on sine-shaped fringes with spatially and temporally varying amplitude, frequency and/or phasing, allows accurate measurement of objects, even with sharp edges or varying surface properties, at high speed.

Our contribution explains the 3D measurement principle and the basic design of a 3D array projector and describes the method how the desired aperiodic sinusoidal fringes are generated. It verifies the consistency between specified and projected patterns and points out the results of the prototype's characterization, e.g. of its high-speed capability. Furthermore, first 3D shape measurements at a frame rate of 5 kHz are presented and evaluated.

9110-15, Session 4

High-speed 3D surface measurement with a fringe projection based optical sensor

Christian Bräuer-Burchardt, Stefan Heist, Peter Kühmstedt, Gunther Notni, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

3D surface measurements become more and more important in industrial quality evaluation and control. Flat objects like conductor boards or wavers are sensitive objects which must fulfill certain quality conditions. We developed an optical sensor based on fringe projection technique for the accurate and fast measurement of the surface of flat objects with a depth extension of ± 0.5 mm. High-speed fringe projection and image recording with 180 Hz allows 3D rates up to 45 Hz.

The sensor realizes three different measurement fields between 22 x 22 mm? and 40 x 40 mm? with lateral spatial solutions between 11 µm and 20 µm with the same working distance. This is realized by a change of the lenses for projection and observation.

Height resolution between 1µm and 5µm can be achieved depending on the properties of the measurement objects.

The sensor is realized using one camera and one projection unit. High-speed recording and data processing can be achieved using epipolar geometry, six- or four-phase algorithm with Gray code omission, and parallel processing. In order to get a sharp projection tilt effect was used for projection and perpendicular arrangement of the camera concerning the measurement object reference plane.

The calibration of the sensor was realized using a new methodology which will be briefly described.

Results of 3D measurements of different objects are presented and discussed.

The proposed sensor does not only suit for industrial inspection tasks but e.g. also for the 3D digitization of flat technical objects.

9110-16, Session 4

Full-field step profile measurement with sinusoidal wavelength scanning Interferometer

Samuel Choi, Osami Sasaki, Takamasa Suzuki, Niigata Univ. (Japan)

A sinusoidal wavelength scanning interferometer for full-field surface profile measurement was developed. The experimental setup consisted of a sinusoidal wavelength scanning laser with a Littman configuration, phase-shift interferometer, and 2-dimensional CCD image sensor. The 3-dimensional surface profile with a step height of 20 micrometer made by two gauge blocks was measured. The interferometric sinusoidal phase changes due to the wavelength shift were estimated by using the four phase shifted interferogram, which contained the initial phase value and amplitude of the modulation. By extracting the initial phase from the Fourier transform of the sinusoidal phase changes, the displacement smaller than the wavelength of the sample surface was obtained with nano-meter accuracy. Furthermore, by extracting the amplitude of the modulation, the optical path difference (OPD) of the step height longer than the wavelength was obtained. By comparing the value that the displacement and the integral multiple of the wavelength were made to add with the OPD of step height, the most approximate integer value is adopted to make the accurate OPD with nano-meter resolution. The synthesized OPD of step heights of a sample with both micrometer scale and nano-meter scale provided a full-field 3-dimensional profile of the sample with long measurement range and high accuracy.

9110-17, Session 5

Advanced roughness and defect metrology solutions *(Invited Paper)*

Erik L. Novak, 4D Technology Corp. (United States)

Cost, weight, performance, and lifetime requirements for precision components used throughout the aerospace and defense industries are driving innovative mechanical designs, manufacturing processes and use of new materials. Additive manufacturing, new ceramics and allows, and In turn, these advanced components typically require tighter dimensional and surface tolerances to function as designed. Scratch testers, microscope-based systems, and other traditional metrology systems are often inadequate for roughness, small-scale geometry, and defect determination on many of these parts.

To meet the growing metrology demand, new technologies are being employed for component qualification. Laser scanners, structured light systems, 3D microscopes, and new stylus products are being developed to address the growing need for robust, versatile, and sensitive measurement of precision components. Each technology has strengths and weaknesses, and no single method is suitable for every metrology task. Determining which product is appropriate to ensure quality and ongoing production control is often difficult due to conflicting definitions and fundamental differences in capabilities between systems.

This talk will compare various metrology methods in terms of lateral and vertical ranges and resolution, suitability to production environments, speed, available analyses, and other critical specifications. Various applications will be discussed and how each system can be evaluated to determine which system or combination of systems is best suited to production control. In addition, definitions of key terms and some common tests that can verify performance will be highlighted so that users can compare disparate systems.

9110-18, Session 5

Development of a small size probe for inner profile measurement of pipes and holes

Toru Yoshizawa, NPO 3D Associates (Japan); Toshitaka Wakayama, Saitama Medical Univ. (Japan); Masayuki Yamamoto, NPO 3D Associates (Japan); Kizuku Machi, Saitama Medical Univ. (Japan)

We have been tryng to develop large and small probes for inner profile meassuremnt of pipes, tubes. and holes. Request for inner profile measurement of pipes and similar objects are becoming larger and larger, and request for measuring smaller inner diameter is strong, that is, probes with smaller oluter diameter are required to meet requirement from various fields such as mechanicalengineering, automobile and aircraft industry and civil engineering.

We have proposed measurement method that incorporates a ring beam device with a laser diode (LD) and a cone mirror inside. Disk-like beam from the ring beam device gives an inner cross-section of the objective. However, recent requst for meauring smaller and smaller inner diameter is vary large, and conventional probes consisting of glass or plastic tubes with such devices as a CCD camera, a cone mirror and LD inside proved too large to realize such smaller diameter as smaller 5mm. Hence we we tried to utilize optical fibers. Up to now, a probe with the size of 5mm in diameter is under trial. When we check the inner surfaces of smaller holes under 5mm in diameter, endoscopes and/or borescopes have been mainly used. However these are not available for capturing inner profiles numerically.

At this stage of development, we are applying the fiber ring beam device in combination with a rigid borescope to attain 5mm-size probe. In adition, we are aiming to realize such a small size probe as 3mm in diameter.

9110-19, Session 5

Development of feature extraction analysis for a multi-functional optical profiling device applied to field engineering applications

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In the real application environment of field engineering, a large variety of metrology tools are required by the technician to inspect part profile features. However, some of these tools are burdensome and only address a sole application or measurement. In other cases, standard tools lack the capability of accessing irregular profile features. Customers of field engineering want the next generation metrology devices to have the ability to replace the many current tools with one single device. This paper will discuss the application of the ring optical gage concept to the measurement of numerous kinds of profile features useful for the field technician. The ring optical system is composed of a collimated laser, a conical mirror and a CCD camera. To be useful for a wide range of applications, the ring optical system requires profile feature extraction algorithms and data manipulation directed toward real world applications in field operation. The paper will discuss such practical applications as measuring the non-ideal round hole with both off-centered and oblique axes. The algorithms needed to analyze other features such as measuring the width of cracks, radius of transition fillets, fall of step surfaces, and surface parallelism will also be discussed in this paper. With the assistance of image processing and geometric algorithms, these features can be extracted with a reasonable performance. Tailoring the feature extraction analysis to this specific gage offers the potential for a wider application base beyond simple inner diameter measurements. The paper will present experimental results that are compared with standard gages to prove the performance and feasibility of the analysis in real world field engineering. Potential accuracy improvement methods and future work will be discussed at the end of this paper.

9110-20, Session 5

A new approach to measure the profile of moving object using triangular fringe pattern profilometry

Jiangtao Xi, Lei Lu, Yanguang Yu, Qinghua Guo, Univ. of Wollongong (Australia)

Fringe pattern profilometry (FPP) is widely used in the 3-D shape measurement of object. Multiple-shot algorithm of FPP needs more than one of the fringe patterns to reconstruct the object. The object must be static when the fringe patterns are projected and captured. Errors will be introduced to the result if the object moves during the measurement. Zhang and Yau used a modified two-plus-one phase shift algorithm to alleviate the errors due to motion. Because the phase value only contains in the first two fringe patterns, the measurement error due to motion is less. Wang and Zhang et al. solved the phase unwrapping errors caused by rapidly moving object. However they cannot reduce the inherent phase error caused by motion. Based on triangular fringe pattern profilometry, this paper proposes an algorithm to measure the object with two dimensional movement. Through analyse the relationship between the movement and intensity values of the fringe patterns, the fringe patterns of object before movement can be recovered by the fringe patterns after movement. Then, the traditional triangular fringe pattern profilometry is used to reconstruct the object. This algorithm can eliminate the errors caused by two dimensional movement of object. The effectiveness is verified by simulations and experiments.

9110-21, Session 5

Deformation kinetics of layered personal protective material under ballistic impact via terahertz reflectometry

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Terahertz dynamic scanning reflectometry (TDSR) was used for characterization of layered materials' deformation kinetics. Multi-layered materials are used for protective devices such as helmet and body armor. An in-situ measurement of deformation and other dynamic characteristics is important when such material is subjected to ballistic impact. Current instrumentation are limited in their ability to provide sub-surface information. A high sensitivity TDSR has been be used to measure dynamic surface deformation characteristics in real-time (in-situ) and at post deformation (ex-situ). Real-time ballistic deformation kinetics was captured with a high speed measurement system. Once, the kinetics is measured, a number of crucial parameters such as deformation length, propagation velocity, final relaxation position, and vibrational motion are extracted from the kinetics spectrum. In addition, layered materials undergo mass loss due impact that needs to be quantified for accurate determination of the trauma conditions. For non-metallic substrates, a transmitted beam was used to calibrate mass loss of laminate layers due to impact. Deformation kinetics information is then used to deduce and validate trauma conditions from blunt hit produced by projectiles. For the present work the Sturdivan criterion [1] was critically examined for helmet materials.

[1]. Sturdivan, L., Viano, D., and Champion, H., "Analysis of injury criteria to assess chest and abdominal injury risks in blunt and ballistic impacts." The Journal of Trauma Injury, Infection, and Critical Care, 2005. 56(651–663).

9110-22, Session 5

Ultra-broadband high-resolution photo acoustic/photo thermal microscopy system for material characterization

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A non-contact ultra-broadband photoacoustic (PA) / photothermal (PT) microscopy system has been developed to characterize material properties of specimens using optical transduction techniques. PT microscopy exploits optical changes induced by heat to highlight the presence of inhomogeneties like defects, contaminants, inclusions, and impurities in materials. A monochromatic light source (pulsed and amplitude-modulated CW) is generally used to create the photothermal effect. The heating of the material consequently produces a stress distribution that launches a broadband ultrasonic emission (PA effect). Measurement of these acoustic emissions can be used to compute the material properties like density, elastic modulus, anisotropy, etc... Using time-reversal and back-propagation techniques, sub-surfaces features in a material can also be detected. In this work, the PT induced refractive index changes as well as the PA effect are detected optically in a Michelson interferometer configuration. The microscopy system has a spatial resolution of ~600 nm with a detection bandwidth of 1 GHz and a displacement sensitivity of 1 pm per root Hz. Experimental results obtained from characterization of thin films, coatings, nanoelectromechanical systems (NEMS) and biological samples will be presented to demonstrate the versatility of the system to function as a nondestructive tool for material characterization.

9110-23, Session 6

Progress in the specification of instruments for areal surface topography measurement *(Invited Paper)*

Peter J. de Groot, Zygo Corporation (United States)

We live in a world of confusing, contradictory and misleading product specifications for metrology instruments that measure 3D surface form and texture. Terms such as "accuracy" and "vertical resolution" populate specification sheets, even though they have no standardized quantitative meaning. Common-knowledge terms such as "lateral resolution" are the subject of spirited debate, with interpretations that vary by a factor of five for the same instrument. Perhaps the worst offender is "repeatability," the specification for which can vary by as much as two orders of magnitude depending on how it is interpreted and evaluated.

In 2005, the International Standards Organization initiated the 25178 document series for areal surface texture standards. Some of the most recent work has been in the development of standards for well-known 3D topography-measuring tools such as confocal, stylus, interference microscopy and focus sensing, encompassing terminology, calibration, verification and good practice. Several of these standards have published, while others are still in development.

Although ISO 25178 standards do not directly address the problem of instrument specification, this paper argues that they can serve as a foundation for this effort. One path is to begin with what ISO identifies as basic metrological characteristics common to all areal surface topography measurement systems, including noise, linearity, the scale factor for determining surface heights, axis perpendicularity and the topographical lateral resolution. For those characteristics quantifiable in a meaningful way on a specification sheet, the ISO standards implicitly provide guidance as to their meaning and verification.

This paper provides an overview of this topic, which still enjoys lively discussion. I present proposals and report progress towards charting a common ground for improved instrument specifications going forward.

9110-24, Session 6

Metrology tool for fast measurement of patterned sapphire structure used in LED manufacturing

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Increasing demand for high-brightness (HB) LEDs is prompting manufacturers to refine production methods and improve performance of LED light sources. Achieving either of these requires high precision metrology tools that are also fast and non-destructive. In particular, there is a need for the metrology for patterned sapphire substrates (PSS) used in LED manufacturing to enhance light-extraction efficiency.

This article describes a gauge-capable metrology tool that is currently used for these purposes: the 3D optical microscope based on white-light interferometer (WLI) which with special algorithms for fringe analysis can specifically quantify the height, width and pitch for each individual PSS structure. We have measured a variety of structures and their dimensions and compared them to SEM or AFM results. For very-high production volumes, even AFMs designed specifically for PSS can be a testing bottleneck. The white-light interferometer (WLI) is a tool that better meets the needs of these applications because of the ease of its full field measurement and for faster defects detection.

3D optical microscopes also provide excellent repeatability, especially when employing the automated position calibration of the reference mirror in the objective and continuous calibration of scanner motion, an option available for production systems. This article will describe the approach to automated reference mirror focusing and its influence on long term stability of measurements.

9110-25, Session 6

Dimensional metrology on semiconductor packaging process using the optical comb

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With the advent of smart devices which are high performance devices with compact size, the semiconductor packaging process has been proposed to realize that. Several silicon wafers were stacked vertically to be 3 dimensional devices for space efficiency. In this process, there are two important parameters to be measured; one is thickness of silicon wafers and the other is depth and diameter of through silicon vias (TSVs) which are vertical holes for electrical connection between stacked silicon wafers. To avoid pattern distortion and failure during an optical lithography process, an absolute value of the thickness as well as its thickness uniformity should be measured. The proposed method can extract geometrical thickness from optical thickness directly. Because shorter TSVs leads disconnection and smaller TSVs may cause voids, both depth and diameter of TSVs are also required to be measured accurately. For these purposes, we have proposed two high-speed optical interferometers based on spectral domain analysis. A light source in use is a femtosecond pulse laser which has advantages of wide-spectral bandwidth, high peak power and long coherence length. The measurement uncertainty of thickness was estimated to be 50 nm (k=1) in the range of 100 mm. The depth and the diameter of the TSVs were measured at the same time with measurement resolution of 10 nm and 100 nm, respectively. It is expected that the proposed interferometers will be used for on-line metrology and inspection as well as new metrological methods for dimensional standards.

9110-26, Session 6

System implementation of self-mixing interferometry technique-based measurement on material parameters

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Material parameters such as Young's modulus (denoted by E), shear modulus (denoted by G) and so on, are intrinsic and valuable quantities for appropriate estimation of material performance. The parameters E and G can be obtained from the resonant frequency from the vibration of the tested material sample excited by an external sweeping frequency source. In this paper, we present a system design for determining the two parameters by using an optical feedback self-mixing interferometry (OFSMI) system. An OFSMI system consists of a laser diode (LD), a micro-lens and an external target. The tested sample is used as the external target. The vibration of the sample causes the variation of the length of the external cavity, and cause a modulated laser power of the LD. The modulation contains the vibration information of the tested samples. The OFSMI system can achieve high measurement accuracy with an extremely simple and inexpensive set-up, thus can be thought as a good candidate for the evaluation of material properties. The system design in this work includes the mechanical part for holding and exciting the tested samples, the optical part for picking up the vibration information from the samples and the system modeling for retrieving the two parameters. In order to accurately determinate E and G, higher vibration mode shapes in a sample are considered. The complex waveform of the LD output power is studied and simulated by using our proposed system model. The proposed method is verified by both simulation and experiments.

9110-27, Session 7

Development of portable 3D optical measuring system using structured light projection method

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Three-dimensional (3D) scanners are becoming increasingly common in many industries. However most of these scanning technologies have some drawbacks in practical use due to size, weight, accessibility, ease-of-use, and so on. Depending on the application - speed, flexibility and portability can often be deemed more important than high accuracy. We have developed to address this market requirement and overcome the aforementioned limitations. To make up for such shortcomings as heavy weight and large size, the optical sensor is used that mainly consists of a laser projector, a camera system, and a multi-touch screen.

Structured laser light is projected on the measured object with a newly designed laser projector employing a single MEMS mirror. The optical system is optimized for the combination of LD, the MEMS mirror and the size of measurement area to secure the contrast of structured light. Also, we develop a new calibration algorithm for this sensor with MEMS laser projector that makes use of simple optical camera model for point cloud calculation.

This technical progress makes the sensor very compact, saves energy consumption, greatly reduces heat generation and be fast at calculation . Due to the principle of the measurement, i.e. structured light triangulation utilizing phase-shifting technology to improve resolution, resolution is improved. To meet the requirements from practical applications, all the optics, electronics, image processing, display and data management capabilities have been integrated into a single compact unit.

9110-28, Session 7

Order and defectivity nanometrology by image processing and analysis of sub-20 nm BCPs features for lithographic applications

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Directed self-assembly (DSA) of block copolymers (BCP) with a high degree of regularity on the 10-100 nm scale is promising a breakthrough to high performance microelectronics applications at dimensions and densities inaccessible to traditional lithography methods. [1] Future success of the application of block copolymer lithography for nanofabrication relies not only on the sub-lithographic dimensions, structure shapes, coverage, etching requirements, but also will require a strict control of the fabricated structures.[2] The keys for success of a production compatible nanometrology system is based on reliable, large-area, inline and robust inspection tools to assure the quality of the fabricated nanostructures. In our recent work on colloidal crystal structures, a positive correlation between the "opposite partner" concept and transmission spectroscopy that probes three-dimensional ordering has been observed. [3] Here we extend this concept to self-assembled BCPs with feature size on the range of 20 nm aiming to employ our technique in samples of phase-separated BCPs as an inline technique. For the purpose, we applied the 'opposite partner' concept, that allows quantitative assessment of order as a function of distance, to the high X BCP systems polystyrene-b-polyethylene oxide (PS-PEO) and polystyrene-b-polydimethylsiloxane (PS-b-PDMS) and having different molecular weights. The periodicity obtained for the films in different annealing conditions and the calculated degree of order, p as a function of the periodicity are studied.

The research leading to these results has received funding from the European Union Seventh Framework Program ([FP7/2007-2013] project LAMAND under grant agreement n° [245565]) and by the Spanish Ministry of Economics and Competitiveness under contract no. MAT2012-31392 (Plan Nacional de I + D + I (2008-2011). The contents of this work are the sole responsibility of the authors.

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9110-29, Session 7

A new fiber optic sensor for hard access area surface roughness measurement

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The accurate measurement of surface roughness is essential in ensuring the desired quality of machined parts. Today the most common method to check roughness is to use a contact stylus profiler. There are many challenges for the application of a contact stylus for measuring the surface roughness of machined parts especially for the hard to access areas such as slots, deep holes and curved pockets. This study proposes a surface roughness measurement technique for these hard to access areas that is based on the measurement of scattered light and the statistical analysis of the light intensity distribution. In order to solve the accessibility issue, a miniaturized fiber optical measurement system (~Ø3mm) was designed using a dual laser emitting configuration. This dual laser approach makes

the system more durable and reliable for different materials and machining processes such as polishing, lapping and precision grinding. This paper will present initial research results that demonstrate the application of this approach to real industrial parts. Tests were performed to evaluate the sensitivity and feasibility of the proposed technique with various machined surfaces and materials.

9110-30, Session 7

Optical design of a structured light phase shift system with no moving parts

Kevin G. Harding, GE Global Research (United States)

3D structured light system based upon phase shifting analysis is well described in the literature. One of the challenges to obtaining high quality data is the noise often associated with the mechanism to shift the projected pattern accurately. The common methods of realizing a phase shift it to either mechanical move a grating pattern that is then projected to the part, or to move the pattern in a programmable projector such as an LCD, LCOS or other projector. These projectors, often made for office use, are limited by the pixel resolution and the stability of the projectors. Mechanical shifts can be very precise, but require time and the maintenance of a mechanical movement. Other systems using projected interference patterns that use piezo shifters are faster and more reliable, but then can suffer from coherent speckle noise. This paper will discuss a unique optical design using a lens made telecentric in image space and an electro-optical image shifting approach that provides very fast image shifts in a very repeatable and controlled manner.

9110-31, Session 7

Optical center alignment technique based on inner profile measurement method

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We have developed inner profile measurement instrumrnt using a ring beam device since 2006. This inner profile measuring technology has attracted great interests for evaluating validity of commercial products in the fields of industry such as automobiles, air planes, heavy industries, energy plants, civil engineering and constructions, and even in medical applications. As our research works expand, there are requirements concerning center alignment from several different fields of industry. For example, this alignment technique is thought to be important to tune up the spindle of precision machines such as a CNC lathe and a machining center. A traditional dial indicator has still been used to adjust the axis by manual operation of engineers and technicians. However, it is not easy to control its axis, precisely. To overcome this issue, we developed an optical centering alignment technique based on our inner profile measurement tool using a ring beam device which consists of a conical mirror and a laser diode. The center position of the cylinder hole can be determined from optically sectioned profiles gotten by the ring beam device. Moreover, we are able to evaluate the tilting angle of the cylinder holes from the ellipsoidal analysis in ellipsometry in the field of polarization measurement. In our trials, the resolution of the center position is proved to be less than 2 micrometers. This technique is available for practical applications in the fields of machine tool industry.

9110-32, Session Posters-Tuesday

High-speed inspection and visualization of fuel injection in the combustion chamber

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This article is focused on the inspection and visualization of fuel injection behavior in a large combustion chamber designed to test nozzles of heavy-duty diesel engines.

Measurement and analysis of fuel injection is very important because optimizing the injection process allows us to reduce emissions and improve the engine performance. As large combustors operate at high speeds of the injected fuel, this process is a high-speed phenomenon. Therefore, the measurement of the ejection is difficult particularly in terms of correct exposure. Using of laser-induced fluorescence presents safety risks, so the designed method of lighting is with light-emitting diode.

The test chamber which meets the requirements for evaluating the quality of ejection (i.e. the analysis of velocity of particles in the fuel flow and the angle of ejection) enabled us to realize the optical measurement with a high- speed camera.

Measurement results are subsequently evaluated by methods of flow tracking and high-speed particle image velocimetry. Visualized results are compared with theoretical expectations obtained by numerical modeling of fuel ejection using the discrete elements method and the rules are designed of how to use these methods in high-speed inspection and visualization of diesel injection in large combustion chambers.

9110-33, Session Posters-Tuesday

Three-dimensional shape measurement system applied to superficial inspection of non-metallic pipings for the hydrocarbons transport

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Three-dimensional shape measurement is a subject that consistently produces high scientific interest and provides information for medical, industrial and investigative applications, among others. In this paper, it is proposed to implement a three-dimensional reconstruction system for applications in superficial inspection of non-metallic piping for the hydrocarbons transport. The system is formed by a CCD camera, a video-projector and a laptop and it is based on fringe projection technique. System functionality is evidenced by evaluating the quality of three-dimensional reconstructions obtained, which allow observing the failures and defects on the study object surface.

9110-34, Session Posters-Tuesday

Facial topographic exploration through a three dimensional reconstruction device with hand-held calibration and multiple acquisitions

Andrés L. González, Carlos R. Contreras, Jaime E. Meneses, Univ. Industrial de Santander (Colombia)

In this paper a novel calibration strategy that allowing the hand-held calibration of a three dimensional reconstruction (R3D) device is proposed, and when it is calibrated then it is use to facial exploration applications. The 3DR device works in base of Fringe Projection Profilometry techniques and it is made up with a video beam and a CCD camera. The calibration strategy was developed at the Universidad Industrial de Santander in Bucaramanga-Colombia; and it is about capture images of a pseudo-periodic points pattern which has been projected over a reference plane. The 3D images of the final reconstruction are the evidence of the calibration strategy functionality, also they allow notice some characteristic details from the human face that has being studied with high accurate. Several reconstructions from different angles are done in order to avoid hidden regions or without information caused by shadows; then they are unified using a registration algorithm of 3D information.

9110-35, Session Posters-Tuesday

Study on the stitching interferometry for the surface profile measurement of a large aperture component

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With the development of the optical technology in present world, the large aperture components have been widely used in many fields. However, it is very difficult to measure a large aperture component. Sub-aperture stitching interferometry can expand longitudinal and lateral dynamic range of standard interferometer and effectively measure the large component with a low cost and high resolution. The key technologies are the partition of sub-aperture, the wave data acquisition of the sub-aperture and the method of positioning and stitching the sub-aperture.

In this paper, the stitching interferometry for the surface profile measurement of a large aperture component is studied. SIFT algorithm is proposed to positioning the sub-aperture. Then the adjacent sub-apertures stitching algorithm, the global error homogenization algorithm and the local error of the equalization algorithm are researched. Furthermore, a principle sub-aperture stitching phase shifting interference system is set up. SIFT algorithm of sub-aperture positioning, interferogram processing, phase unwrapping, Zernike polynomials wave fitting and sub-aperture's wave-front stitching programs are written. The surface profile of a component is measured with the principle system. The results of comparing stitching and full caliber testing have been given, the RMS deviation of these two methods is less than 2nm. Thus positioning the sub-aperture with SIFT algorithm and relevant programs written above are verified.

9111-1, Session 1

Observations of ocean diurnal variations from the Korean geostationary ocean color imager (GOCI)

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The first geostationary ocean color satellite sensor, Geostationary Ocean Color Imager (GOCI) onboard the Korean Communication, Ocean, and Meteorological Satellite (COMS), which was launched in June of 2010 and has eight spectral bands from the blue to the near-infrared (NIR) wavelengths in 412–865 nm, can monitor and measure ocean phenomenon over a local area of the western Pacific region centered at 36°N and 130°E and covering ~2500 x 2500 km2. Hourly measurements during daytime (i.e., eight images per day from local 9:00 to 16:00) are a unique capability of GOCI to be used for the short- and long-term regional ocean environmental monitoring. In this paper, we show some more recent results of GOCI-measured ocean diurnal variations in various coastal regions of the Bohai Sea, Yellow Sea, and East China Sea. With possibly eight-time measurements daily, GOCI provides a unique capability to monitor the ocean environments in near real-time, and GOCI data can be used to address the diurnal variability in the ecosystem of the GOCI coverage region. In addition, more in situ data measured around the Korean coastal regions are used to validate the GOCI ocean color data quality, including evaluation of ocean diurnal variations in the region. The GOCI results demonstrate that GOCI can effectively provide real-time monitoring of water optical, biological, and biogeochemical variability of the ocean ecosystem in the region. Finally, mission-long GOCI ocean color data are used to characterize seasonal and interannual variations in water optical, biological, and biogeochemical properties in the western Pacific region.

9111-2, Session 1

Calibration uncertainty in ocean color satellite sensors and trends in long-term environmental records

Kevin R. Turpie, Univ. of Maryland, Baltimore County (United States) and Joint Ctr. for Earth Systems Technology (United States); Robert E. Eplee Jr., SAIC (United States); Bryan A. Franz, Carlos Del Castillo, NASA Goddard Space Flight Ctr. (United States)

Launched in late 2011, the Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the Suomi National Polar-orbiting Partnership (NPP) spacecraft is being evaluated by NASA to determine whether this sensor can continue the ocean color data record establish through the Sea-Viewing Wide Field-of-view Sensor (SeaWiFS) and the MODerate resolution Imaging Spectroradiometer (MODIS). To this end, Goddard Space Flight Center generated evaluation products using calibration techniques and algorithms established by NASA during the SeaWiFS and MODIS missions. In particular, the calibration trending was subjected to careful sensitivity and uncertainty analyses. Here we present an assessment of how the NASA-produced time series of ocean color is influenced by uncertainty in trending instrument response over time. The results help quantify the uncertainty in measuring regional and global biospheric trends in the ocean using satellite remote sensing, which better define the roles of such records in climate research.

9111-3, Session 1

Impacts of the VIIRS processing procedures on the retrievals of ocean color data products in coastal regions

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As part of the Ocean Color (OC) component of the Aerosol Robotic Network, the Long Island Sound Coastal Observatory (LISCO) near New York City, and WaveCIS in the Gulf of Mexico, expand OC observational capabilities with continuous monitoring, as well as (for the LISCO site) additional assessment of the hyper-spectral properties of coastal waters. In the investigations carried out over almost a two year period of VIIRS data for the two coastal sites, it has been observed that the VIIRS normalized water leaving radiance (nLw) data exhibits significant correlations with in-situ data. Impacts of the different VIIRS vicarious and temporal calibration procedures on the nLw data retrieval accuracies have been examined and the performance of the atmospheric correction procedure in data processing scrutinized. For the WaveCIS site, VIIRS nLw data retrievals are enhanced with each incremental adjustment of vicarious and temporal calibration procedures. However, that is not the case for the LISCO site which exhibits more frequent occurrences of negative water-leaving radiances, while underestimation is further exacerbated. Newly installed Water Quality Monitoring (WQM) instrument at LISCO provides time series data of Colored Dissolve Organic Matter, Chlorophyll concentration [Chl] and turbidity, and thus, together with comprehensive above water measurements, enhanced capabilities in the validation of OC products as well as making assessments of the retrieval performances of OC processing algorithms are afforded. The consequences of the uncertainties in nLw data on the VIIRS [Chl] data in coastal waters are also examined based on WQM and LISCO's water and atmospheric measurements.

9111-4, Session 1

Sensitivity of calibration gains to ocean color processing in coastal and open waters using ensembles members for NPP-VIIRS

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The sensitivity of ocean color products to variations in vicarious calibration gains at Top of Atmosphere (TOA) shows varying impacts in different water types for Suomi- NPP VIIRS satellite . Blue water vicarious gains from MOBY in situ data, which is used for global open waters, and green water gains derived from complex coastal WaveCIS AERONET waters, have a different impact on spectral normalized water leaving radiances and the derived ocean color products (inherent optical properties, chlorophyll). We evaluated the influence of a linear interpolation of gains from open and coastal waters by establishing a set of ensemble-processed products. The TOA gains show a non-linear impact on derived ocean color products, since gains affect multiple ocean color processing algorithms such as atmospheric correction, NIR iterations, etc. We show how the variations within the ensemble TOA gain members spatially impact derived products from different water types (high CDOM, high backscattering, etc). The spatial distribution of the mean and variance of ensemble gain members

is presented to characterize the product uncertainty in coastal and open ocean water types. The results of the ensemble gain members are evaluated with in situ matchups. Results suggest the sensitivity of the ocean color processing for open ocean verses coastal waters.

9111-5, Session 1

VIIRS reflective solar bands calibration changes and potential impacts on ocean color applications

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The VIIRS (Visible-Infrared Imaging Radiometer Suite) instrument onboard the Suomi NPP (National Polar-orbiting Partnership) spacecraft started acquiring Earth observations in November 2011. Since then, radiometric calibration applied to the VIIRS RSB (Reflective Solar Band) measurements for the SDR (Sensor Data Record) production has been improved several times. Initially, radiometric calibration coefficients were updated once per week to correct for the responsivity degradation that occurs for some of the sensor's spectral bands due to contamination of the VIIRS telescope's mirrors. Despite the frequent updates, discontinuities in the radiometric calibration could still affect ocean color time series. In August 2012, magnitude of the radiometric coefficient changes was greatly reduced by implementing a procedure that predicts (about a week ahead) values of the calibration coefficients for each Earth scan until a subsequent update. The updates have been continued with the weekly frequency, and coefficient prediction errors were monitored and compared with uncertainties of the initial invariant coefficients. The radiometric coefficient updates were temporarily suspended during the partial shutdown of the US government operations in October 2013. A potential increase in uncertainty of the VIIRS RSB radiometric calibration was monitored during the shutdown, and the predicted coefficients were compared with the coefficients derived once per orbit from the onboard solar diffuser measurements by an automated procedure, called RSBAutoCal, scheduled for the implementation in the VIIRS SDR operational processing in November 2013. The paper evaluates the changes in the VIIRS RSB coefficient updates and potential impacts on ocean color applications. Preliminary comparisons between the calibration coefficients generated by the RSBAutoCal and the current operational versions are also presented.

9111-6, Session 1

Inter-satellite comparison and evaluation of Navy Suomi-NPP VIIRS and MODIS aqua ocean color properties

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Navy operational ocean color products of inherent optical properties and radiances are evaluated for the Suomi–NPP VIIRS and MODIS-Aqua sensors. Statistical comparisons with shipboard measurements were determined in a wide variety of coastal, shelf and offshore locations in the Northern Gulf of Mexico and U.S. East Coast. Product consistency between MODIS-Aqua, nearing its end-of-life expectancy, and Suomi-NPP VIIRS is being evaluated for the Navy to retrieve accurate ocean color properties operationally from VIIRS in a variety of water types. Currently, the existence, accuracy and consistency of multiple ocean color sensors (VIIRS, MODIS-Aqua) provides multiple looks per day for monitoring the temporal and spatial variability of coastal waters. Consistent processing methods and algorithms are used in the Navy's Automated Processing System (APS) for both sensors for this evaluation. The inherent optical properties from both sensors are derived using a coupled ocean-atmosphere NIR correction extending well into the bays and estuaries where high sediment and CDOM absorption dominate the optical signature. Coastal optical properties are more complex and vary from chlorophyll-dominated waters offshore. The in-water optical properties were derived using vicariously calibrated remote sensing reflectances for multiple inherent optical product algorithms (Quasi Analytical Algorithm – QAA, Linear Matrix Inversion – LMI). The Naval Research Laboratory (NRL) and the JPSS program have been actively engaged in calibration/validation activities for Visible Infrared Imager Radiometer Suite (VIIRS) ocean color products.

9111-7, Session 1

Evaluation of in-situ radiometric data processing for calibration and validation of satellite ocean color remote sensing

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In-situ data are essential for calibration, validation, and bio-optical algorithm development of ocean color remote sensing, as well as for studying and understanding ocean optical, biological, and biogeochemical properties. Especially, calibration and validation of ocean color satellite data relies on high quality in-situ data. In addition, objective evaluation of satellite ocean color products need well quality controlled in-situ data from various bio-optical environments covering diverse aquatic waters. The goal of ocean color satellite sensors is to remotely derive accurate normalized water-leaving radiance spectra (nLw(λ)), so that other water biological and biogeochemical property data can be obtained using satellite-measured nLw(λ) spectra. In this presentation, we show results from analyzing in-situ data processing procedure from the Marine Optical Buoy (MOBY) and NASA SeaWiFS Bio-optical Archive and Storage System (SeaBASS) used for satellite ocean color calibration and validation purposes. Various issues in determining final product of in-situ radiometric data processing such as convolving nLw(λ) with respect to satellite sensor spectral response functions, sensor effective band wavelengths, and effects of Bi-directional Reflectance Distribution Function (BRDF) are analyzed and discussed. Performance of satellite-derived nLw(λ) spectra taking into consideration various issues in in-situ data processing is also assessed.

9111-8, Session 1

Sea surface salinity in coastal waters of the Gulf of Mexico using visible channels on Suomi-NPP

Ryan A. Vandermeulen, Robert A. Arnone, The Univ. of Southern Mississippi (United States); Sherwin D. Ladner, U.S. Naval Research Lab. (United States); Martín A. Montes-Hugo, Paul M. Martinolich, Planning Systems Inc. (United States)

Sea surface salinity is determined using the visible channels from the Visual Infrared Imager Radiometer Suite (VIIRS) to derive regional algorithms for the Gulf of Mexico, normalized to seasonal river discharge. The dilution of river discharge with open ocean waters and the surface salinity is estimated by tracking the surface spectral signature. The water leaving radiances (nLw) derived from atmospherically-corrected and calibrated 750-m resolution visible M-bands (410, 443, 486, 551, 671 nm) are applied to bio-optical algorithms and subsequent multivariate statistical methods to derive regional empirical relationships between satellite radiances and surface salinity measurements. Although radiance to salinity is linked to CDOM dilution, we explored improved statistical relationships to account

for starting conditions. In situ measurements are obtained from over 20 moorings spread across the Gulf of Mexico including coverage of the Mississippi Sound, Mobile Bay, Galveston Bay, Louisiana Shelf, Tampa Bay, and West Florida Shelf, with a salinity range of 0.1 - 35. In addition to examining regional differences, data were collected over all seasons in the year 2013 in order to assess inter-annual variability. The seasonal spectral signatures at the river mouth were used to track the fresh water end members and used to develop a seasonal slope and bias between salinity and radiance. Although not as accurate as Aquarius Microwave salinity, results show an increased spatial resolution for remote detection of coastal sea surface salinity from space. Coastal surface salinity has significant impact on the physical circulation which impacts the coastal ecosystems. Results identify locations and dissipation of the river plumes and provide improved data assimilation for physical circulation models.

9111-9, Session 1

Relationship between sea surface salinity from l-band radiometer and optical features in the East China Sea

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During the monsoon season, the East China Sea (ECS) is often obscured from space in the visible and near-visible bands by cloud cover, which prevents remote sensing retrieval of optical properties. However, clouds are transparent to microwave and satellites with L-band radiometers have recently been put into orbit to monitor sea surface salinity (SSS). The usual relationship between Colored Dissolved Organic Matter (CDOM) and salinity in fluvially impacted coastal regions has been used in previous studies to obtain SSS from satellite retrieved CDOM (Ahn et al., 2008). In this study, the relationship is used in the reverse sense to estimate CDOM from remotely sensed SSS in the ECS. SSS data are obtained from the L-band radiometers on the European Space Agency's Soil Moisture and Ocean Salinity satellite and on NASA's Aquarius satellite. CDOM retrieved from NASA Aqua satellite and from the L-band radiometers are compared during absent cloud cover. Challenges in using this approach are that 1) L-band SSS retrieval has coarse resolution (35-100 km), 2) the ECS is notorious for having anthropogenic sources of radiofrequency interference (ARGANS, 2012; JPL, 2012) which adds noise to the SSS retrievals, and 3) as the coast is approached, land brightness begins to contaminate the side lobes of the antennae. Despite the limits imposed on the accuracy and spatial resolution of remotely sensed SSS, qualitatively distributed CDOM in the ECS can be obtained. Further research is required to fully understand the limits to quantitatively characterizing the CDOM distribution in the ECS from L-band radiometry.

9111-10, Session 1

Reducing ocean surface specular reflection in worldview-2 images

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Exploitation of satellite and aircraft imagery for ocean color applications is limited by the extent to which an accurate atmospheric correction can be accomplished. Characterizing specular reflection off the sea surface is one component of this correction. The WorldView-2 configuration with two multi-spectral focal planes separated by the panchromatic focal plane and a 0.2 second offset in data collection between the two multi-spectral focal planes creates a challenging specular reflection correction scenario. On June 11, 2010 DigitalGlobe, Inc. imaged the Moreton Bay, Australia region seven times between 00:26:07 and 00:27:55 GMT with the WorldView-2 sensor. The atmosphere was exceptionally clear as confirmed by AERONET data collected at the University of Queensland in Brisbane. Specular reflection varied widely among the seven images. With the rapid imaging of the sequence of images other atmospheric and oceanic variable elements can be assumed to be effectively constant making this dataset ideal for testing glint reduction techniques. Glint reduction techniques are compared to identify which technique results in the least variable image sequence of remote sensing reflectances and greatest reduction of spatial glint-induced variability within a glint contaminated image.

9111-11, Session 1

Validating Landsat 8 for mapping aquatic environments

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The operational Land Imager (OLI) aboard Landsat 8 was launched in February 2013 to continue the Landsat's mission of monitoring earth resources at relatively high spatial resolution. Comparing to the Landsat heritage sensors, OLI has enhanced features, including the 12-bit radiometric resolution and the addition of a 443-nm band, which make it superior for mapping aquatic environments. This study presents early evaluations of Landsat 8 (OLI) radiometric performance over coastal waters. While its top-of-atmosphere (TOA) radiance observations are compared with those of ocean color missions, the remote sensing reflectance (Rrs) products are also examined using in-situ measurements. Early evaluations of OLI's applications for near-shore, bottom mapping are also presented.

9111-12, Session 2

Sea-surface temperature from Suomi-NPP VIIRS: algorithm development and uncertainty estimation *(Invited Paper)*

Peter J. Minnett, Robert H. Evans, Guillermo P. Podestá, Katherine A. Kilpatrick, Univ. of Miami (United States)

The Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership satellite (Suomi-NPP), launched on October 28, 2011, is the first in a new series of visible and infrared radiometers to be flown on the Joint Polar Satellite System (JPSS). Four of the infrared channels of VIIRS were designed to provide accurate retrievals of skin SST. The infrared detectors were cooled down in early 2012 and the data stream stabilized in early March. The objectives of the Miami group include refining the SST retrieval algorithms, both cloud screening and atmospheric correction, in a way that provided continuity with the heritage instruments and deriving estimates of the skin SST retrieval accuracies. These are facilitated by comparisons with other sources of SSTs, including drifting buoys and microwave fields from WindSat. Also, infrared radiometers have been deployed on commercial and research vessels to provide skin temperature measurements, for independent assessment of the SST retrieval uncertainties and to provide a path for VIIRS to contribute to the SST Climate Data Record.

9111-14, Session 2

SST algorithms in ACSPO reanalysis of AVHRR GAC data from 2002-2013

Boris Petrenko, Global Science & Technology, Inc. (United States) and NOAA Ctr. for Weather and Climate Prediction (United States) and National Environmental Satellite, Data, and Information Service (United States); Xinjia Zhou, Cooperative Institute for Research in the Atmosphere (United States); Alexander Ignatov, NOAA Ctr. for Weather and Climate Prediction (United States)

4 km resolution GAC data from several AVHRR instruments flown on NOAA and MetOp satellites from 2002-2013 have been reprocessed with Advanced Clear-Sky Processor for Oceans (ACSPO) to create a consistent L2 SST product, for the use in NOAA geo-polar blended SST and potentially other L4 products. The SST retrieval algorithms for reprocessing were selected and developed with specific emphasis on

1) minimizing spatial biases in retrieved SST;

2) closely reproducing magnitudes of true SST variations (i.e. ensure that sensitivity of retrieved SST to true SST is close to 1);

3) maximizing temporal stability of biases

Two types of SST algorithms were explored: Conventional regression (CR), the mainstream operational algorithm, and recently developed Incremental Regression (IncR), which correlates deviations of SST from reference L4 SST field with deviations of observed brightness temperatures from radiative transfer simulations.

The CR equations were adopted in the EUMETSAT OSI-SAF formulation, which, according to the previous analyses, provide optimal combination of minimal spatial/angular biases with high sensitivity, in its class. The IncR equations were elaborated to specifically optimize the empirical bias correction, and to satisfy the criteria 1) and 2). The criterion 3) was satisfied by recalculation of both CR and IncR coefficients on a daily basis using a 3-months sliding window of daily matchups spanning ±45 days around the current date. This presentation describes the SST algorithms adopted for reprocessing and evaluates the resulting L2 SST product.

9111-15, Session 2

Evaluation of ACSPO-reanalysis 2002-2013 time series for self- and cross-consistency

Xinjia Zhou, NOAA Ctr. for Weather and Climate Prediction (United States); Prasanjit Dash, National Environmental Satellite, Data, and Information Service (United States); Alexander Ignatov, Boris Petrenko, NOAA Ctr. for Weather and Climate Prediction (United States)

Long-term consistent time series of Level2/3 SST products are needed for producing high-quality L4 SST products. Recently, 4 km resolution GAC data from several AVHRR instruments flown on NOAA and MetOp satellites from 2002-2013 have been reprocessed using NOAA Advanced Clear-Sky Processor for Oceans (ACSPO) system. Work is underway to extend these time series, initially back 1994, and later back to 1981. ACSPO-RAN L2 data will be blended with geostationary SST data to produce the NOAA geo-polar L4 SST product, for the use in the Coral Reef Watch monitoring. This presentation evaluates ACSPO-RAN L2 product from 2002-2013 and compares it with other existing long-term L2/L3 SST time series, such as the PATHFINDER v5.2 L3 product from NOAA AVHRR GAC, and MOD28/MYD28 L2 product from AQUA and TERRA MODIS. The three SSTs are consistently evaluated against several long-term L4 and in situ SSTs. Work is underway to report the results of evaluation in the NOAA web-based SST Quality Monitor (SQUAM, www.star.nesdis.noaa.gov/sod/sst/squam/).

9111-16, Session 2

Exploring enhancements to ACSPO VIIRS cloud mask based on SST pattern analyses: potential and limitations *(Invited Paper)*

Irina Gladkova, The City College of New York (United States); Fazlul Shahriar, The Graduate Ctr., The City Univ. of New York (United States); Yury Kihai, Boris Petrenko, Alexander Ignatov, NOAA Ctr. for Weather and Climate Prediction (United States)

Discriminating clear ocean from cloud is challenging, especially at night. Threshold in automated cloud detection algorithms are often set conservatively and tend to underestimate the SST domain. Yet an expert user can usually distinguish the cloud patterns from SST. In this study, we explore an automated pattern recognition approach. We discuss available methodologies to differentiate cloud and ocean patterns. Analyses are performed with the SST retrieved from VIIRS sensor onboard S-NPP using NOAA ACSPO system. Using hand-selected globally-representative ACSPO VIIRS SST images, we have identified low level spectral and spatial features likely useful for discriminating cloud from clear ocean. These features include spatial connectivity of SST deviation Reynolds SST, as well as some statistics the gradient field. Using these features, a cluster based approach allows automatic segmentation into regions. These regions then form the basis for additional cloud tests through training a statistical classifier using expert labeled data. We will present the potentials and limitations of such an approach and discuss various features that can be used to identify typical patterns and textures.

9111-17, Session 2

Reduction of striping for improved ACSPO SST imagery derived from S-NPP VIIRS and terra/aqua MODIS clear-sky radiances

Marouan Bouali, NOAA Ctr. for Weather and Climate Prediction (United States) and Cooperative Institute for Research in the Atmosphere (United States); Alexander Ignatov, NOAA Ctr. for Weather and Climate Prediction (United States)

Residual scan line noise in level 1B clear-sky radiances derived from multidetector imaging spectroradiometers like VIIRS and MODIS, although within sensor pre-launch specifications, adversely affects the image quality of level 2 SST products. The resulting striping reduces the geometrical homogeneity of full sensor resolution SST and therefore degrades its usefulness for the study of ocean dynamics.

An adaptive destriping algorithm based on image processing techniques was recently designed to improve the quality of NOAA's Advanced Clear-Sky Processor for Ocean (ACSPO) SST products.

In this paper, we illustrate the long term performance of this algorithm in terms of image quality enhancement and analyze its impact on the global statistics of full sensor resolution SST. One month of level 1B data from S-NPP VIIRS and Terra/Aqua MODIS have been processed for stripe noise reduction prior to ingestion in the ACSPO system. Results indicate a stable and positive impact on the visual quality of SST imagery as well as on the detection of thermal fronts and the global statistics of SST.

9111-18, Session 2

Effect of consistent CRTM coefficients on M-O bias and DDS in micros

XingMing Liang, NOAA Ctr. for Weather and Climate Prediction (United States) and Colorado State Univ. (United States) and Cooperative Institute for Research in the Atmosphere (United States); Alexander Ignatov, NOAA Ctr. for Weather and Climate Prediction (United States); Yong Chen, Univ. of Maryland, College Park (United States)

Community Radiative Transfer Model (CRTM) minus observation (M-O) biases, and corresponding double differences, DD=-[(M-O)-(M-O)ref], are calculated over clear-sky ocean @3.7, 11 and 12µm for several AVHRR, MODIS and VIIRS sensors, and monitored in the Monitoring of IR Clear-Sky Radiances over Oceans for SST (www.star.nesdis.noaa.gov/sod/sst/micros) system. For the use of DDs to quantify cross-platform biases, the M and Mref must be calculated accurately and consistently. The M terms are defined by the "CRTM coefficients", calculated by fitting the training set of line-by-line (LBL) RTM calculations, set of training profiles, and gases.

Two transmittance algorithms are employed, the Optical Depth in Absorber Space (ODAS) and the Optical Depth in Pressure Space (ODPS), along with two fit methods - the ordinary (ORD) and Planck Weighted (PW). The ODPS-PW M-O biases and DDs appear more accurate. Some DDs (e.g., between AVHRRs and MODISs/VIIRS groups up to ~0.4K) may be due to the M term, e.g. suboptimal parameterization of the Chlorofluorocarbons (CFC) absorption in LBL, whereas some others (e.g., in some bands of Metop-A and –B, and Terra and Aqua up to ~0.3K) are likely to sensor inconsistencies. Work between SST and CRTM Teams is underway to resolve these remaining differences.

9111-19, Session 2

Polar SST and clear-sky radiance products and monitoring at NOAA

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NOAA produces operational and experimental SST and ocean clear-sky ocean radiances products from VIIRS, AVHRR and MODIS sensors using heritage Advanced Clear-Sky Processor for Oceans (ACSPO) system. In 2011, NOAA also assumed responsibility for the JPSS Interface Data Processing Segment (IDPS) SST product. All SSTs are routinely monitored and validated in the SST Quality Monitor (SQUAM; www.star.nesdis.noaa.gov/sod/sst/squam/). Quality controlled n situ data come from the in situ SST Quality Monitor (iQuam; www.star.nesdis.noaa.gov/sod/sst/iquam/). ACSPO clear-sky radiances are monitored in the Monitoring of IR Clear-sky Radiances over Oceans for SST (MICROS; www.star.nesdis.noaa.gov/sod/sst/micros/). Current status is discussed.

9111-20, Session 2

Towards Cal/Val of Sentinel-3 SST in NOAA SST quality monitor: initial evaluation of A(A)TSR reprocessing for climate (ARC)

Prasanjit Dash, Alexander Ignatov, National Environmental Satellite, Data, and Information Service (United States); Boris Petrenko, Yury Kihai, National Environmental Satellite, Data, and Information Service (United States) and Global Science & Technology, Inc. (United States)

European Sentinel3 satellite is planned for launch in 2014-15. It will carry SLSTR radiometer, which builds upon A(A)TSRs flown onboard ERS/ENVISAT. NOAA supports Cal/Val of SLSTR SST in SST Quality Monitor (SQUAM: www.star.nesdis.noaa.gov/sod/sst/squam), which currently monitors several SST products from AVHRR, MODIS, and VIIRS. Towards Sentinel3 readiness, A(A)TSR Reprocessing for Climate (ARC) dataset is being added in SQUAM. If A(A)TSR/SLSTR SST proves superior to the SST derived from US sensors, it may be used to anchor global AVHRR, MODIS and VIIRS SST products. Initial analyses of ARC SST and inter-comparisons with AVHRR-MODIS-VIIRS SST products in SQUAM are presented.

9111-45, Session 2

Analysis of the VIIRS cloud mask: comparison with the NAVOCEANO cloud mask and how they complement each other

Jean-François P. Cayula, QuinetiQ North America, Inc. (United States); Douglas A. May, Bruce D. McKenzie, Naval Oceanographic Office (United States)

The Visible Infrared Imager Radiometer Suite (VIIRS) Cloud Mask (VCM) Intermediate Product has been developed for use with Suomi National Polar-orbiting Partnership VIIRS Environmental Data Record (EDR) products. In particular, the VIIRS Sea Surface Temperature (SST) EDR relies on VCM to identify cloud-corrupted observations. Unfortunately, VCM does not appear to perform as well as cloud detection algorithms for SST. This may be due to the the closely related but not identical goals of the two algorithms: While the purpose of VCM is to detect clouds, that of the SST cloud detection is to identify clear observations. The result is that in undetermined cases VCM defaults to "clear," while the SST cloud detection defaults to "cloud." This problem is further compounded because classic SST cloud detection often flags all types of corrupted data as "cloud," thus making a comparison with VCM difficult. The Naval Oceanographic Office (NAVOCEANO), which operationally produces a VIIRS SST product, relies on cloud detection from the NAVOCEANO Cloud Mask (NCM), adapted from cloud detection scheme designed for SST processing. To analyze VCM, the NAVOCEANO SST process was modified to attach VCM flags to all SST retrievals. Global statistics are computed for both day and night data. The cases where NCM and/or VCM tag data as "cloud-corrupted" or "clear" can then be investigated. By analyzing the VCM individual test flags in conjunction with the status of NCM, areas where VCM can complement NCM are identified.

9111-13, Session Posters-Tuesday

Comparison of VIIRS SST fields obtained from differing SST equations applied to a region covering the northern Gulf of Mexico and western North Atlantic *(Invited Paper)*

Jean-François P. Cayula, QuinetiQ North America, Inc. (United States); Douglas A. May, Naval Oceanographic Office (United States); Ryan A. Vandermeulen, The Univ. of Southern Mississippi (United States)

Several groups produce Sea Surface Temperature (SST) retrievals derived from data acquired by the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on board the Suomi National Polar-orbiting Partnership satellite. Because of varying requirements or past experience, the groups often use differing SST equations to make their retrievals. Here, we compare and discuss the equations through an examination of the SST fields. In most cases, the fields are created using the same program but with differing equations, while in other cases, such as for the Interface Data Processing Segment Environmental Data Records, SST fields are directly produced by other groups. Also discussed is how applying different coefficients for one equation affects the SST retrievals, and, how different first guess SST fields for the non-linear SST equations affect the SST retrievals in coastal and open waters. This study focuses on a region covering the northern Gulf of Mexico and part of the western North Atlantic. The evaluation tries to minimize the effect of data contamination, such as clouds, on the results by matching the best satellite-derived SST value in a neighborhood to the value from drifting or moored buoys. Results based on the region under study are linked back to global statistics computed daily at the Naval Oceanographic Office.

9111-38, Session Posters-Tuesday

Underwater pressure measurement using fibre optic extrinsic Fabry-Perot interferometric (EFPI) sensors

Dinesh Babu Duraibabu, Sven Poeggel, Elfed Lewis, Thomas Newe, Univ. of Limerick (Ireland)

Ocean has vital impact on our climate and weather. An in-situ sensor which can be placed in Buoys, moorings and Remote operated underwater vehicle (ROV's) can be benefited along with the other emerging sensing technologies. Optical fibres are immune to electromagnetic radiation and have a small loss compared to other state-of-the-art techniques (Maximum attenuation <0.2 dB/km), which makes them ideal for long distance measurements like in deep ocean. A fibre optic extrinsic Fabry Perot Interferometer (EFPI) sensor is developed for monitoring pressure in the underwater and sub-seabed under simulated conditions. The sensor is robust in design and is fabricated entirely from Silica glass (i.e. no water absorbing material was used). The EFPI is formed at the tip of the fibre, where the single mode is spliced to a 200μm capillary, sealed by a 200μm Multimode, which forms the diaphragm. The diaphragm thickness is reduced by polishing and etching with hydrofluoric (HF) acid to about 2-3μm for a high sensitivity. The thickness of the diaphragm is monitored online during polishing and HF etching. The spectrum of the fibre optic sensor (FOS) is interrogated using a broad band optical light source and an optical spectrometer. The sensitivity of the sensor achieved is 1.5cmH2O, excellent for small depth-changes. Experimental measurements with saturated salt water and chlorophyll pigmentation of different standards were tested, to simulate the sub-sea conditions where a stability of 2cmH2O/h was reached with a drift of less than 10% under the simulated conditions.

9111-39, Session Posters-Tuesday

A model-based ELM for atmospheric correction over Case 2 water with Landsat 8

Javier A. Concha, Rochester Institute of Technology (United States)

The Landsat-8 satellite, recently launched (February 2013), carries the next generation of Landsat sensors and extends over 40 years of continuous imaging acquisition. Landsat-8, with its improved spectral coverage and radiometric resolution, has the potential to dramatically improve our ability to simultaneously retrieve the three primary coloring agents (chlorophyll, colored dissolved organic material, and suspended material) from water bodies and considering its 30-meter resolution should be especially useful for studying the nearshore environment.

In the Case 2 water problem, accurate atmospheric correction is essential yet remains a significant source of water-constituent retrieval error particularly since the sensor-reaching signal due to water is very small compared to the signal from atmospheric effects and the black target assumption is not valid due to water-leaving signal in the NIR in turbid water. In this work, a modified version of the empirical line method (ELM) has been developed, which utilizes reflectance from both an in-water radiative transfer model (HydroLight) and a reflectance product (Landsat surface reflectance product) to atmospherically correct Landsat-8 images. This method employs pseudo-invariant feature (PIF) pixel extraction to mask urban landscape from the reflectance product for the bright pixel determination. For the dark pixel, HydroLight is used to obtain the field spectra that replace ground-truth measurements normally used in the ELM. The radiance values for the dark and bright pixels are extracted from the corresponding regions in the Landsat-8 image. Initial results of this method are compared to results obtained from a traditional ELM and to ground-truth data as well.

9111-40, Session Posters-Tuesday

The impact of turbulent fluctuations on light propagation in a controlled environment

Silvia Matt, Weilin Hou, Wesley Goode, U.S. Naval Research Lab. (United States)

Underwater temperature and salinity microstructure can lead to localized changes in the index of refraction and can be a limiting factor in oceanic environments. This optical turbulence can affect electro-optical (EO) signal transmissions that impact various applications, from diver visibility to active and passive remote sensing. To quantify the scope of the impacts from turbulent flows on EO signal transmission, and to examine and mitigate turbulence effects, we perform experiments in a controlled turbulence environment allowing the variation of turbulence intensity. This controlled turbulence setup is implemented at the Naval Research Laboratory Stennis Space Center. Convective turbulence is generated in a classical Rayleigh-Bénard tank and the turbulent flow is quantified using a state-of-the-art suite of sensors that includes high-resolution Acoustic Doppler Velocimeter profilers and fast thermistor probes. The measurements are complemented by very high-resolution non-hydrostatic numerical simulations. These computational fluid dynamics simulations allow for a more complete characterization of the convective flow in the laboratory tank than would be provided by measurements alone. Optical image degradation in the tank is assessed in relation to turbulence intensity. The results from the laboratory experiments and numerical simulations are also put into the context of field observations of optical turbulence. The unique approach of integrating optical techniques, turbulence measurements and numerical simulations helps advance our understanding of how to mitigate the effects of turbulence impacts on underwater optical signal transmission, as well as of the use of optical techniques to probe oceanic processes.

9111-41, Session Posters-Tuesday

Vicarious calibration and regional adjustment of coastal VIIRS

Jennifer B. Bowers, Planning Systems Inc. (United States); Robert A. Arnone, The Univ. of Southern Mississippi (United States); Sherwin D. Ladner, U.S. Naval Research Lab. (United States); Paul M. Martinolich, Planning Systems Inc. (United States); Giulietta S. Fargion, San Diego State Univ. (United States); Adam Lawson, U.S. Naval Research Lab. (United States); Ryan A. Vandermeulen, The Univ. of Southern Mississippi (United States)

As part of the JPSS Ocean Cal/Val Team, NRL-SSC has been working to facilitate calibration and validation of VIIRS ocean color products. By modifying the NASA Ocean Color Biology Group methodology for vicarious calibration of ocean color satellites and utilizing the AERONET-OC system to provide in situ data, we are able to investigate difference between remotely sensed water leaving radiance and the expected in situ response in coastal areas and compare the results to traditional MOBY calibration/validation activities.

The results support arguments that the current satellite calibration methods, utilizing in oligotrophic Case 1 waters leave room for improvement with respect to satellite products in coastal Case 2 waters. The data also support the concept of applying regional calibrations to improve coastal products however; the significant challenge posed by regional adjustment lies in quantifying the uncertainty.

9111-42, Session Posters-Tuesday

Development of an aerosol microphysical and optical model in the marine and coastal environments

Gennady A. Kaloshin, V.E. Zuev Institute of Atmospheric Optics (Russian Federation)

It is known, that changes in the concentration, and distribution of sea-salt aerosol is important for predict the performance of EO systems, the precipitation efficiency of clouds, change cloud amount, their properties that influence on the radiative forcing of the climate system.

Their impact on clouds, being superimposed on the aerosol generated by an open ocean, varies greatly with the meteorological parameters, such as wind speed.

Based on the facts the presented investigation seeks to contribute to a better understanding of cloud-active sea-salt aerosol and optical effects of marine aerosol eventually aiming for a development of a robust algorithm for the aerosol extinction forecast.

In the study, we consider the coastal physical effects and ocean processes as functions of the wind speed, its direction, fetch, relative humidity and altitude above the sea level. While taking into account the variability of marine and coastal aerosols, the paper focuses on the detailed description of the developed aerosol model and the optical properties of the aerosol. We discuss the developed algorithm and the comparison of our results calculated by the software product MaexPro (Marine Aerosol Extinction Profile) with observational data.

9111-43, Session Posters-Tuesday

Developing a universal classification tree model for mapping aquatic vegetation in Taihu Lake using different phase HJ-CCD image

Juhua Luo, Ronghua Ma, Xianfeng Zhou, Nanjing Institute of Geography and Limnology (China)

Aquatic vegetation play an important role in maintaining the balance of the lake ecosystem thus classifying and mapping aquatic vegetation is a priority of lake management. Remote sensing techniques can provide spatial and temporal information about aquatic vegetation. Classification trees (CT) have been used successfully in the past to classify aquatic vegetation from spectral indices obtained from remotely-sensed images. However, due to the effects of extrinsic and intrinsic factors, application CT model developed for certain date image to another date image can reduce the classification accuracy. In this study, these spectral features (SFs) were derived by principal component (PC) transform, tasseled cap (PC) transform and band combination and their potential in identifying emergent vegetation, floating-leaf vegetation and submerged vegetation were tested. Then three spectral features (SFs) were selected out to develop CT model for identifying aquatic vegetation in Taihu Lake. Three traditional CT models (TCT1, TCT2, TCT3 model) with three SFs were developed using CT analysis based on HJ images acquired on 11 July, 16 August and 26 September 2013 and corresponding ground-truth samples, with overall accuracies are 82.14 % for TCT1 model, 79.72 % for TCT2 model and 84.36 % for TCT3 model. Further, a new method was proposed to modify the thresholds of SFs in TCT model and developed modified CT model (MCT) for applying to another date image. The method for developing MCT model was assessed and validated by accuracy relative to actual ground-truth samples and area agreement between the classified maps created using MCT model and TCT model. Our results suggested that the method was feasible and could be used to develop MCT model for mapping aquatic vegetation in any date image other than the one for which the model was developed.

9111-44, Session Posters-Tuesday

VIIRS reflective solar bands on-orbit calibration

Junqiang Sun, Global Science & Technology, Inc. (United States); Menghua Wang, NOAA Ctr. for Weather and Climate Prediction (United States)

The Visible Infrared Imaging Radiometer Suite (VIIRS) is one of five instruments onboard the Suomi National Polar-orbiting Partnership (NPP) satellite which was launched on Oct. 28, 2011. It has 22 spectral bands, among which 14 are Reflective Solar Bands (RSBs). The RSBs are used to generate the VIIRS ocean color data products, which requires the RSBs are calibrated with high accuracy and long-term stability. The instrument was characterized and calibrated prelaunch. The on-orbit gain changes of the RSBs are mainly tracked by on-board Solar Diffuser (SD) calibration every orbit. The instrument is also scheduled to observe the Moon approximately monthly, which is used to derive the on-orbit changes for the RSBs as well. In this paper, the VIIRS SD and lunar calibrations are reviewed and the derived calibration coefficients, called F factors (inversely proportional to the gains), for the RSBs are analyzed. The coefficients derived from the two calibrations are compared and the uncertainties of the calibrations are discussed.

9111-46, Session Posters-Tuesday

Algorithms for the remote estimation of chlorophyll-a in the Chesapeake Bay

Ioannis Ioannou, The City Univ. of New York (United States); Alexander Gilerson, The City College of New York (United States); Michael E. Ondrusek, NOAA Ctr. for Weather and Climate Prediction (United States); Robert Foster, The City College of New York (United States); Ahmed El-Habashi, Kaveh Bastani, The City Univ. of New York (United States); Samir Ahmed, The City College of New York (United States)

Remote estimation of chlorophyll-a concentration [Chl] in the Chesapeake Bay from reflectance spectra is challenging because of the optical complexity and variability of the water composition as well as atmospheric corrections for this area. This work is focused on algorithms for near surface measurements. The performance of several well established global inversion algorithms and ones that use the red/NIR part of the spectrum are analyzed together with recently developed multiband inversion algorithms that combine wavelengths in the blue, green and red and compared with field data, which consisted of the NOMAD for Chesapeake Bay region as well as results from our field campaigns in 2005 and 2013 with the full range of measurements of water optical properties as well as chlorophyll concentrations and specific absorption spectra from in water samples.

Algorithms were then developed, using neural networks, and trained on a simulated data generated through bio-optical models typical for a broad range of coastal water parameters, and specifically for those known for the Chesapeake Bay, as well on direct relationships between reflectance spectra and [Chl] acquired by the NOMAD contributors and from our own field measurements. Special attention was paid to the field data consistency in both reflectance and [Chl] measurements to avoid undesirable biases and trends. All algorithms were finally evaluated by several statistical indicators to arrive at the best candidates for further applications to satellite data.

9111-47, Session Posters-Tuesday

Implications of a new phase function for autonomous underwater imaging

Charles C. Trees, Ctr. for Maritime Research & Experimentation (United States); Georges R. Fournier, Defence Research and Development Canada, Valcartier (Canada); Violeta Sanjuan Calzado, Ctr. for Maritime Research & Experimentation (Italy)

Autonomous underwater vehicles do not have sufficient communications bandwidth over long ranges to send back real time images even for monitoring purposes. Autonomous imaging from underwater vehicles will therefore require real-time imaging system performance prediction in order to ensure that the vehicle can position itself at a range that will allow it to take an image of the scene or target of interest at the required resolution and contrast level. Ideally the inherent optical properties of the surrounding waters should be measured on board. This may not be feasible or only a restricted set may be measurable. In order to improve the prediction of the imaging performance, a physics based analytic phase function that could effectively exploit any a-priori or in-situ measured parameters would be extremely helpful. Such a new physics based analytic phase function has been derived and tested against exact scattering codes. Among other features it is sufficiently precise to allow an accurate determination of the backscatter ratio based on an estimate of the mean index of refraction which is by far the dominant parameter. The new formulation shows clearly why the backscatter ratio, which is the dominant factor in determining imaging range, is insensitive to the inverse power of the size distribution and almost entirely controlled by the mean index of refection. Using a simple formulation for the mean index the formula has been tested against data collected in the Ligurian Sea.

9111-21, Session 3

Multistatic optical imaging system

Derek M. Alley, Linda J. Mullen, Naval Air Systems Command (United States); Brandon Cochenour, Alan Laux, Naval Air Warfare Ctr. Aircraft Div. (United States)

Typical line-of-sight (LOS)/monostatic optical imaging systems include a laser source and receiver that are co-located on the same platform. The performance of such systems is deteriorated in turbid ocean water due to the large amount of light that is scattered on the path to and from an object of interest. A bistatic architecture, which puts the laser and receiver on separate, smaller platforms, has been developed to help extend the range of underwater optical imaging systems and to provide more operational flexibility. Although the laser must be within 4 attenuation lengths of the object to minimize forward-scattered light, the receiver can be located many more attenuation lengths away since all the light scattered from the object – even the multiply scattered light – carries 'useable' information about the object. The laser is modulated with information concerning how the laser scans the object, and the receiver decodes this information to create the image. Therefore, the transmitter and receiver are entirely autonomous and are linked only via a wireless communication signal that is carried by the light scattered from the object and from the environment. Recently, a multistatic configuration has been demonstrated where multiple transmitters and receivers are used to provide backscatter suppression and target range information. The paper will review recent controlled laboratory experiments conducted to evaluate the effectiveness of the multistatic underwater optical imaging system at producing higher quality 2D images and supplementing 2D images with 3D range data to aid in object identification.

9111-22, Session 3

Compressive sensing active serial imaging system for the underwater environment

Bing Ouyang, Frank M. Caimi, Fraser R. Dalgleish, Gero Nootz, Walter Britton, Anni K. Vuorenkoski, Harbor Branch Oceanographic Institute (United States)

In recent years, the OVOL lab at HBOI at FAU proposed the Compressive Sensing (CS) based active serial imager (CSASI). One of the main focuses was to develop this concept into an effective imaging system in the scattering and absorbing medium such as the turbid ocean water. Two different configurations were proposed – a frame based approach that is advantageous for stationary platforms such as hover-capable autonomous underwater vehicles (HAUV) and another technique that adopts the whiskbroom image formation and is more compatible with tradition survey platforms: the compressive line sensing technique. The compressive line sensing exploits both the intra-signal sparsity and the correlation among adjacent areas that is common for the natural underwater scenes through the theoretical foundation of distributed compressive sensing (DCS). The initial simulations and the clear water experimental results demonstrated the feasibility of the proposed concepts. This paper intends to gain more in-depth understanding of the performance of CSASI in the turbid ocean water through additional simulations and experimental study. System induced interferences such as motion artifacts and receiver noise under different conditions (i.e. turbidities) are studied. Sensing model that incorporates such understanding and techniques to improve the system performance by effectively alleviate such interference are investigated. Optical design considerations that impact the performance of the prototype system used in the test tank experiments are analyzed. Results from simulations and turbidity cycle in the HBOI test tank are presented.

9111-23, Session 3

Underwater imaging of polarized targets

Alexander Gilerson, Yalong Gu, Carlos Carrizo, Amir Ibrahim, Ahmed El-Habashi, Robert Foster, Samir Ahmed, The City College of New York (United States)

Attenuation of light in seawater by both water molecules and hydrosols usually results in blurring and degradation of an image even over short distances. Some of both natural and manmade objects in sea water have partially polarizing surfaces, whose properties can be exploited for the purpose of camouflaging or, conversely, for facilitating detection and imaging of polarized targets. Restoration of targets' optical characteristics using underwater imaging technique in various aquatic environments is of a great interest for the scientific community. In this work, we present the analysis of images of several underwater targets that exhibits different polarization properties measured using an underwater camera in various water conditions from clear ocean waters to highly turbid waters such as the Chesapeake Bay.

The measurements using the full Stokes polarization imaging camera are compared with an imaging model. The model combines vector radiative transfer simulations using the RayXP program for the propagation of light in the atmosphere-interface-ocean (AIO) system and the Monte Carlo simulations for the near horizontal imaging in the water. Modeling includes analysis of the vector point spread function (PSF) from the target and the contribution of the veiling light between the target and the camera. Results are further used for more comprehensive analysis of the propagation of polarized light and imaging in water. Several algorithms for the retrieval of the polarization characteristics of underwater targets from the image are also evaluated.

9111-24, Session 3

Overview of a hybrid underwater camera system

Philip M. Church, Neptec Technologies Corp. (Canada); Weilin Hou, U.S. Naval Research Lab. (United States); Fraser R. Dalgleish, Harbor Branch Oceanographic Institute (United States); Georges R. Fournier, Defence Research and Development Canada, Valcartier (Canada)

The paper provides an overview of a Hybrid Underwater Camera (HUC) system combining sonar with a range-gated laser camera system. The sonar is the BlueView P900-45, operating at 900kHz with a field of view of 45 degrees and ranging capability of 60m. The range-gated laser camera system is based on the third generation LUCIE (Laser Underwater Camera Image Enhancer) sensor originally developed by the Canadian National Defence. LUCIE uses an eye-safe laser generating 1ns pulses at a wavelength

of 532nm and at the rate of 20kHz. An intensified CCD camera operates with a gating mechanism synchronized with the laser pulse. The gate opens to let the camera capture photons from a given range of interest and can be set from a minimum of 5ns with increments of 200ps. The output of the sensor is a 30Hz video signal. Automatic ranging is achieved using a sonar altimeter. The sonar and LUCIE sensors are integrated with an underwater computer that controls the sensors parameters and display the real-time data for the sonar and the laser camera. As an initial step for data integration, graphics overlays representing the laser camera field-of-view and the width of the gate are overlaid on the sonar display. The HUC system can be manually handled by a diver and can also be controlled from a surface vessel through an umbilical cord. Recent test data obtained from the HUC system operated in a natural underwater environment will be presented along with measured performance characteristics.

9111-25, Session 3

Waveform design considerations for modulated pulse lidar

Shawn P. O'Connor, Linda J. Mullen, Naval Air Warfare Ctr. Aircraft Div. (United States)

Optical imaging and ranging of underwater objects is of special interest to the Navy. This task is made difficult by the optical propagation characteristics of water and environmental clutter. Techniques have been developed to mitigate many of the issues associated with underwater imaging in turbid environments but as targets get smaller and better camouflaged new techniques are needed to keep pace. NAVAIR has been developing several techniques that use RF modulation to suppress background clutter and enhance target detection. One approach in particular uses a modulation encoded pulse in a synchronous line scan configuration. Previous results have shown this technique to be effective at both forward and backscatter suppression. Nearly a perfect analog to modulated pulse radar, this technique can leverage additional signal processing and pulse encoding schemes to further suppress background clutter, pull signals out of noise, and improve image resolution. Additionally, using a software controlled transmitter, we can exploit this flexibility without the need to change out expensive hardware. Various types of encoding schemes were tested and compared. We report on their comparative effectiveness over single frequency modulation to suppress background clutter and improved target detection.

9111-27, Session 4

Underwater channel identification using a 532nm chaotic lidar transmitter and adaptive filtering

Luke K. Rumbaugh, David W. Illig, Clarkson Univ. (United States); Todd A. Wey, Lafayette College (United States); William D. Jemison, Clarkson Univ. (United States)

The underwater channel presents a challenging operating environment for modulated lidar systems, but understanding the channel's effects on the transmitted modulation signal can allow significant performance improvements. Knowledge of the channel's modulation response is especially beneficial in scatter-limited operation. For example, backscatter loses modulation depth at high frequencies (>100 MHz), and several successful ranging and imaging systems have leveraged this fact to deliver improved performance in turbid waters. However, the degradation of the signal due to forward scatter also increases with increasing modulation frequency. Thus for best performance, the operating modulation frequency range must be high enough to allow suppression of backscatter, but not be so high that the target return is irreparably corrupted by forward scattering. Since the modulation frequency response of the channel depends on the ever-changing suspended particle distributions in the water, an instantaneous measurement of the channel modulation response is desirable to inform the choice of modulation used.

In this paper we introduce an underwater channel identification system capable of real-time measurement of the water's modulation response function. The optical source used is a custom fiber-laser based 532 nm chaotic lidar transmitter that delivers a noise-like wideband modulation signal. Using this transmitter in conjunction with a digital adaptive filter, the water channel's effect on the lidar signal is modeled, and the frequency response of the channel is determined. Individual backscatter and forward scatter responses are measured, as well as the composite channel response function with a target in a monostatic ranging/imaging arrangement.

9111-28, Session 4

Optical ranging techniques in turbid waters

David W. Illig, William D. Jemison, Clarkson Univ. (United States); Robert W. Lee, NAVAIR Training Systems Division (United States); Alan Laux, Linda J. Mullen, Naval Air Systems Command (United States)

Laser-based range finders offer the possibility for high-precision range accuracy in the underwater environment. These systems experience exponential losses due to scattering and absorption of photons. Absorption reduces received signal power, while scattering produces a "clutter" signal.

The performance of two ranging approaches in turbid waters will be presented. The first approach uses a dual frequency modulation to reduce ambiguity and achieve high range precision. The second approach uses stepped frequency modulation to achieve long unambiguous range and single-tone modulation to achieve fine range precision. Results from laboratory experiments using each technique will be presented and compared to model predictions.

9111-29, Session 4

The impact of oceanic gravity waves on laser propagation

Serdar Kizilkaya, Turkish Navy Research Ctr. (Turkey); Timothy Kane, The Pennsylvania State Univ. (United States)

The usage of lasers in ocean studies is widespread. Each step of laser beam propagation through the ocean is a major topic to be analyzed, often independently. The objective of this study is to specifically focus on the interaction of the laser beam with the air-ocean interface and the modeling and analysis of the effects of a gravity wave perturbed ocean surface on laser propagation. The directional energy spectrum of Neumann with the Fourier series expansion is used in a Monte Carlo simulation of the gravity wave perturbed ocean surface model. Beam tracing with the ABCD matrix approach is used for the laser beam propagation analysis rather than using the ray tracing like in many similar studies. Specific parameters are used in the model to output not only a qualitative model but also numerical and realistic results. The main purposes of this study are implementing a numerical model to see the effects of the ocean surface on laser propagation and analyzing the feasibility of using the beam tracing approach in such a model.

9111-30, Session 4

Optical remote sensing of sound in the ocean

James H. Churnside, National Oceanic and Atmospheric Administration (United States); Konstantin Naugolnykh, Zel Technologies, LLC (United States); Richard D. Marchbanks, Univ. of Colorado at Boulder (United States) and National Oceanic and Atmospheric Administration (United States)

We are proposing a novel remote sensing technique to measure sound in the upper ocean. The objective is system that can be flown on an aircraft. Conventional acoustic sensors are ineffective in this application, because almost none (~ 0.1 %) of the sound in the ocean is transmitted through the water/air interface. The technique is based on the acoustic modulation of bubbles near the sea surface. It is clear from the ideal gas law that the volume of a bubble will decrease if the pressure is increased, as long as the number of gas molecules and temperature remain constant. The pressure variations associated with the acoustic field will therefore induce proportional volume fluctuations of the insonified bubbles. The lidar return from a collection of bubbles has been shown to be proportional to the total void fraction, independent of the bubble size distribution. This implies that the lidar return from a collection of insonified bubbles will be modulated at the acoustic frequencies, independent of the bubble size distribution. Moreover, that modulation is linearly related to the sound pressure. The basic principles have been demonstrated in the laboratory, and these results will be presented. Estimates of signal-to-noise ratio suggest that the technique should work in the open ocean. Design considerations and signal-to-noise ratios will also be presented.

9111-31, Session 4

Beyond bathymetry: probing the ocean subsurface using ship-based lidars

Charles C. Trees, Ctr. for Maritime Research & Experimentation (United States)

A 'proof-of-concept' for the maritime application of a ship-based LIDAR system for measuring the optical and physical properties in the water column is presented that includes documenting that there exists today the engineering, modeling and optical expertise to accomplish this task as well as reasons why LIDAR has not become the powerful observational platform that it should have been for horizontally and vertically monitoring optical properties. Previous research on this approach has been limited because LIDAR systems have for most cases not been thoroughly calibrated, if at all, nor have LIDARs been focused on above–water ship-based measurements. Efforts at developing derived product algorithms with uncertainties have been limited. This review concludes that there is a huge potential for the successful application of LIDAR measurements in the marine environment to estimate the vertical distribution of optical and that measurement costs can be minimized by deployment of these automated systems on 'ships-of-opportunity' and military vessels on a non-interfering basis. Although LIDAR measurements and research have been around since the 1960's, this approach has not really been investigated by any civilian or military agencies or laboratories even though providing 'through-sensor performance matrixes' for existing bathymetry, target detection, under communication and underwater imaging should be high on their list.

9111-32, Session 5

Gliderpalooza 2013: so much more than gliders

Michael F. Crowley, Oscar Schofield, Scott M. Glenn, Rutgers Coastal Ocean Observation Lab. (United States)

Gliderpalooza represents a grass-roots coordinated field demonstration of ocean observing technologies spanning the eastern seaboard of North America that grew out of the MARACOOS and Ocean Tracking Networks science priorities. The goal was to coordinate disparate ocean efforts, funded by a variety of agencies to demonstrate continental scale coordination of various ocean observing technologies to sample ecologically relevant scales. The integrated data was collected to serve a range of science goals while also providing a regional data set for hindcast studies that can be used to improve future physical, optical and ecological modeling/sampling efforts. The coordinated data from satellites, HF-RADAR, moorings, drifters, meteorological towers and models was focused around the distributed deployment of 16 Slocum gliders deployed during the fall transition months of September and October. The timing was chosen to coincide with the peak months of animal migrations, the fall transition from the summer stratified ocean to well mixed winter conditions, the peak in tropical cyclone activity, and when undergraduates can utilize ocean observing data using NSF OOI web-based learning tools to engage a new generation of oceanographers.

9111-33, Session 5

The Chesapeake Bay interpretive buoy system: an estuarine observing partnership

William D. Wilson, Caribbean Wind LLC (United States)

The Chesapeake Bay Interpretive Buoy System (CBIBS; http://buoybay.noaa.gov) is now a six-year-old operational observing system. Buoys are regularly used, inter alia, for water quality monitoring, marine weather forecasting, remote sensing and model validation, tracking endangered Atlantic Sturgeon, and as a basis for educational curricula. The NOAA Chesapeake Bay Office (NCBO), which developed and implemented the CBIBS, has recently partnered with the Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS) to support CBIBS operations and maintenance and to expand the range and capability of the system. Through this partnership, a new buoy in the James River has recently extended the original ten-buoy CBIBS system. Additional platforms are being tested and considered for the system: Low-cost Basic Observation Buoys, Nutrient-sensor enhanced platforms for Chesapeake Bay tributaries, and Ocean Acidification / Carbon monitoring buoys.

The system has been conceived and designed with consideration for Global Ocean Observing System (GOOS) principles; and it can be considered a starting point for the further development of the US Integrated Ocean Observing System (IOOS) into the estuarine environment. In the process of describing the System, its components, data, and products, we will show how CBIBS follows three sets of concepts important to the IOOS: Core Variables, Societal Benefit Areas, and Subsystem Structure. By maximizing System alliance with these principles, CBIBS provides broad utility, robust and flexible infrastructure, portability and expandability, and perhaps most important, a diverse and enthusiastic user base.

9111-35, Session 5

Airborne remote sensing investigation of shoaling internal waves, eddies, and rip currents on the inner shelf

Geoffrey Smith, George O. Marmorino, W. David Miller, U.S. Naval Research Lab. (United States)

Several recent field exercises undertaken by the Naval Research Laboratory have provided a unique data set covering the boundary of the inner self and surf zone near Huntington Beach, CA. The focus of the study was to understand the behavior of surf zone eddies, their formation process, evolution, and contribution to other processes such as sediment transport. However, in addition to the surf zone eddies internal waves and rip currents were imaged. The spatial and temporal scales of these processes are somewhat difficult to resolve; we present data captured from a small aircraft with rapid revisit times to provide temporal information while still capturing the synoptic scales. The data were captured via an airborne suite of remote sensing instruments including visible/near infrared hyperspectral imagery and mid-wave infrared imagery. We attempt to shed some light on the overall statistics of the features imaged, such as diameter, wavelength, and drift velocity. Their role in sediment transport and interaction with internal waves and rip currents will also be discussed.

9111-36, Session 5

The validation of ocean color sensors using a profiling hyperspectral radiometer

Michael E. Ondrusek, NOAA Ctr. for Weather and Climate Prediction (United States); Eric Stengel, National Oceanic and Atmospheric Administration (United States)

Validation measurements of ocean color sensors require in situ measurements that are accurate, repeatable and traceable enough to distinguish variability between in situ measurements and variability in the signal being observed. The utility of using a Satlantic Hyperpro II radiometer for validating ocean color sensors is tested by analyzing the uncertainty in the measurements and processing. This is done by comparing Hyperpro in situ measurements to other instruments and between different Hyperpros in a variety of water types. Calibration and characterization of the NOAA Satlantic Hyperpro instrument is described and concurrent measurements of water-leaving radiances conducted during cruises are presented between this profiling instrument and other profiling, above-water and moored instruments. The moored optical instruments are the US operated Marine Optical BuoY (MOBY) and the French operated Boussole Buoy. In addition, Satlantic processing versions are analyzed for accuracy and consistency. A new multi-cast approach is compared to the most commonly used single cast method. Analysis comparisons are conducted in turbid and blue water conditions. Examples of validation matchups with VIIRS ocean color data are presented. With careful data collection and analysis, the Satlantic Hyperpro profiling radiometer has proven to be a reliable and consistent tool for satellite ocean color validation.

9111-37, Session 5

Remote real-time sensing technology for gaseous hydrocarbon concentration measurement in deep water layers from joint Russian-Ukraine R&D team

Andrey Bashchenko, GeoSpex (Russian Federation); Sergiy Baschenko, Institute of Physics (Ukraine)

For the purpose of gaseous hydrocarbons dissolved trace concentrations detection and measurement, one can use the fact, that hydrocarbons molecules are Raman active. That means, while probing laser radiation propagates through water media, hydrocarbon molecules will scatter the probing radiation with a characteristic frequency shift, inherent for this particular hydrocarbon. Part of this Raman scattered radiation will inevitably be emitted in the direction of probing system, where it can be collected, filtered by frequency to get rid of background and noise radiation, and measured to estimate hydrocarbons concentration.

Implementation of remote method requires resolution of the following problem. Sea water is also Raman active itself, and it's Raman spectra overlaps Raman spectra of methane. Methane concentration in seawater is relatively low, thus Raman shifted radiation of water is much higher than those of methane molecules.

Authors are going to solve this task during research.

In a physical sense, the method researched is based on the combination of Raman spectroscopy and methods of modulation spectroscopy (spectroscopy derivatives, etc.). It is assumed that a certain (well-founded and correct) their combination will combine their advantages, such as: remoteness and selectivity inherent to the method of Raman scattering and high selective sensitivity with high noise immunity inherent for the modulation (but at the moment only due absorbance - i.e. with strictly limited range) spectroscopy methods.

At the moment research is in progress, with first results being obtained for investigation of Raman spectra of water, and investigation of Raman phenomena for methane dissolved in water.

9112-1, Session 1

NIH/NIDCR perspective on non-invasive disease diagnostics based on oral fluids *(Invited Paper)*

Isaac R. Rodriguez-Chavez, Penny W. Burgoon, National Institute of Dental and Craniofacial Research (United States)

No Abstract Available

9112-5, Session 1

Rapid saliva test for HIV/AIDS screening and monitoring

Sarka O. Southern, Gaia Medical Institute (United States)

No Abstract Available

9112-6, Session 1

Wireless, quantitative, and universal lateral flow test reader

Sophie Gerrick, Ray C. Delcher, Onur Mudanyali, Neven Karlovac, Holomic LLC (United States)

Responding to the disease (e.g., HIV) markers and chemical/biological (e.g., anthrax) agents, color changes and variations on immuno-chromatographic lateral flow tests (rapid diagnostic tests - RDTs) indicate the presence of the threats and epidemics. We recently introduced a novel cell-phone based quantitative lateral flow test reader that utilizes a cordless hardware attachment and an android application running on the same cell-phone. Integrated into the cloud using GSM and/or other wireless networks, this rugged cell-phone reader enables quantitative analysis of immuno-chromatographic tests with exceptional performance, providing coefficient of variation (CV) smaller than 1% and limit of detection (LOD) of ~0.8% optical density (OD).

The snap-on hardware attachment can be repeatedly attached-detached to the cell-phone device and fully encloses the custom-designed opto-mechanical interface that is used to acquire the enhanced images of rapid tests via the cell-phone camera. Weighing less than 8 oz., the reader attachment is powered by an additional cell-phone battery that is embedded into the same attachment. It can accommodate and evaluate more than five different test types (e.g., anthrax, HIV, bacterial, afla-toxins, and cardiac rapid tests) using its smart tray design without any need for external mechanical components or adaptors. Running custom-designed image processing algorithms, the cell-phone application rapidly processes the raw images and generates a quantitative analysis of the test results which can be uploaded to the cloud. This universal and quantitative platform may provide a highly-accurate and sensitive tool to screen emerging epidemics and other threats and contribute to generate a real-time spatiotemporal surveillance system.

9112-7, Session 1

Programmable bio-nano-chip system for non-invasive disease diagnostics

John McDevitt, Rice Univ. (United States)

No Abstract Available

9112-8, Session 1

Saliva-based molecular test for malaria

Sungano Mharakurwa, Johns Hopkins Univ. (United States)

No Abstract Available

9112-69, Session 1

KS-detect: solar-thermal PCR for smartphone assisted diagnosis of Kaposi's sarcoma in limited resource settings and its potential application to using oral fluids

David Erickson, Li Jiang, Matthew Mancuso, Zhengda Lu, Cornell Univ. (United States); Gunkut Akar, Ethel Cesarman, Weill Cornell Medical College (United States)

In this talk, I will describe a method that harnesses sunlight to drive chemical amplification of viral DNA and demonstrate that this enables low-power smartphone-based molecular diagnostics in resource-limited settings. The high power requirements and complexities of current polymerase chain reaction (PCR) devices severely restrict their availability in low-infrastructure settings. Even with the development of isothermal PCR techniques, reports of power consumption have not improved over the last decade. We eliminate the energy burden of thermal cycling and the need for many electrical components by converting sunlight directly into heat to power PCR. Our system reduces power consumption by 2 orders of magnitude compared to commercial products, enabling 70 h of battery life when used with a standard iPhone. Finally, we combine this with low-power methods for DNA extraction and detection to demonstrate a strategy for nucleic acid testing that is completely powered by sunlight and a smartphone. This work combines solar energy and smartphone technology to address significant engineering challenges in global health. As the most abundant energy sources on Earth, sunlight is utilized here for the novel application of DNA amplification. Similarly, smartphones have quickly become nearly ubiquitous in many parts of the world and are finding an increasing number of applications in medical diagnostics. By developing a PCR technique that utilizes sunlight and smartphones, we hope to provide nucleic acid-based diagnostics to the most resource-limited and remote regions of the world.

9112-71, Session 1

Rapid noninvasive tests for diagnostics of infectious disease

Daniel Malamud, New York Univ. (United States)

No Abstract Available

9112-72, Session 1

Micro- and nano-scale medical technologies for Global Health applications

Utkan Demirci, Harvard Medical School (United States)

No Abstract Available

9112-73, Session 1

Next-gen microblotting for confirmatory disease diagnostics

Amy Herr, Univ. of California, Berkeley (United States)

No Abstract Available

9112-9, Session 2

Nanosensor for saliva based glucose monitoring

Jonathan C. Claussen, U.S. Naval Research Lab. (United States)

No Abstract Available

9112-10, Session 2

Oral microbiome: a role in dynamic proteomics of whole saliva

Eva J. Helmerhorst, Boston Univ. (United States)

Human saliva is a complex human body fluid due to the various contributions from exocrine as well as non-exocrine sources. The exocrine sources are the salivary glands which produce oral fluid containing the secretory proteins. Non-exocrine constituents are desquamated epithelial cells, PMNs, microorganisms, and a serum-like transudate called gingival crevicular fluid. The non-sterile oral environment causes substantial proteolytic processing of salivary proteins. LC-ESI-MS/MS analysis of the <10 kD fraction of mixed saliva showed that many of the proteolytic peptides were formed through a post-glutamine cleavage event. In search of the origin of the proteases we observed that glutamine endoprotease activities were negligible in sterile glandular salivary secretions, but highly enriched in dental plaque. The microbial glutamine endoproteases did not only target salivary but also dietary proteins that are rich in glutamines called gluten. Gluten proteins are implicated in celiac disease, which is an inflammatory disorder of the small intestine. Gluten proteins are difficult to digest by mammalian digestive enzymes. One of the therapeutic approaches for celiac disease that are currently being pursued is to achieve fragmentation and neutralization of immunotoxic gluten epitopes through enzymatic digestion. The newly discovered gluten-degrading oral microorganisms and their glutamine-specific endoproteases are promising new candidates to be explored as novel therapeutic agents in the treatment of celiac disease and gluten-sensitivity.

9112-11, Session 2

Human saliva proteome: an overview *(Invited Paper)*

Timothy J. Griffin, Univ. of Minnesota (United States)

No Abstract Available

9112-13, Session 2

Saliva biomarkers in cardiovascular disease *(Invited Paper)*

Craig S. Miller, Univ. of Kentucky (United States)

No Abstract Available

9112-14, Session 2

Salivary biomarkers for modeling breast cancer progression *(Invited Paper)*

Charles F. Streckfus, The Univ. of Texas Health Science Ctr. at Houston (United States)

No Abstract Available

9112-15, Session 2

The diagnostic potential of bacterial glycan recognition in saliva

Stefan Ruhl, Univ. at Buffalo (United States)

No Abstract Available

9112-17, Session 2

Top down protein analysis for characterizing health and disease

Julian Whitelegge, Univ. of California, Los Angeles (United States)

No Abstract Available

9112-18, Session 3

Rehabilitation technologies for traumatic brain injury and stroke *(Invited Paper)*

Mary E. Michel, National Institutes of Health (United States)

Rehabilitation aimed at TBI or stroke must start with accurate diagnosis based on evolving brain changes, but finding biomarkers of brain "disease" is challenging. Research on assessing brain-specific markers in blood, CSF or saliva could provide rapid diagnosis and prevent second injury. Recent findings from patients with repeated brain trauma indicate an evolving neurodegeneration, which requires changing rehabilitation strategies to overcome worsening cognitive and motor deficits. Reliable biomarkers, either from fluids or advanced imaging techniques, need to be developed, simplified, and brought into clinical practice. Successful rehabilitation requires knowledge of patients' chage over time: are approaches working, is the patient achieving goals, are other systems deteriorating, are additional services needed? Assessing "brain change" will require new IT approaches to storing, accessing and sharing data. To move rehabilitation forward for TBI (and stroke) research is needed on biomarkers, patient-centered treatment, and data sharing.

9112-20, Session 3

The military's approach to TBI and PTSD *(Invited Paper)*

Geoffrey Ling, Uniformed Services Univ. of the Health Sciences (United States)

No Abstract Available

9112-21, Session 3

Sports-related traumatic brain injury: prevention and rehabilitation *(Invited Paper)*

Barry D. Jordan, Sports Concussion Institute (United States)

No Abstract Available

9112-22, Session 3

Clinical detection of brain damage in TBI

Ava M. Puccio, Univ. of Pittsburgh Medical Ctr. (United States)

No Abstract Available

9112-23, Session 3

New approach to neurorehabilitation: cranial nerve noninvasive neuromodulation (CN-NINM technology)

Y. Danilov, K. Kaczmarek, M. Tyler, Univ. of Wisconsin-Madison (United States)

Cranial-Nerve Non-Invasive NeuroModulation (CN-NINM) is a primary and complementary multi-targeted rehabilitation therapy that initiates the recovery of multiple damaged or suppressed brain functions that are affected by neurological disorders. It is deployable as a point-of-need device (portable tongue neurostimulator, PoNSTM). The device is simple and easy to use by lay users following initial patient training in an outpatient clinic. It may be easily combined with all existing rehabilitation therapies, and may reduce or eliminate need for more aggressive invasive procedures or decrease the total medication intake. CN-NINM uses sequenced patterns of electrical stimulation on the tongue. Our hypothesis is that CN-NINM induces neuroplasticity by noninvasive stimulation of two major cranial nerves: trigeminal, CN-V, and facial, CN-VII. This stimulation excites a natural flow of neural impulses to the brainstem (pons varolli and medulla), and cerebellum, to effect changes in the function of these targeted brain structures, extending to corresponding nuclei of the brainstem. CN-NINM represents a synthesis of a new non-invasive brain stimulation technique with applications in physical medicine, cognitive, and affective neurosciences. Our new stimulation method appears promising for treatment of a full spectrum of movement disorders, and for both attention and memory dysfunction associated with traumatic brain injury.

9112-24, Session 3

Saliva-based biomarkers for TBI diagnostics

Sarka O. Southern, Gaia Medical Institute (United States)

No Abstract Available

9112-25, Session 4

Monitoring physiology during spaceflight *(Invited Paper)*

Virginia E. Wotring, Universities Space Research Association/NASA JSC (United States)

During spaceflight missions, NASA crewmembers experience months of ordinary medical events, as well as certain syndromes associated with the unusual environment of spaceflight. It is well documented from current and past missions that many spaceflight-associated alterations are observed in human physiology, including changes in bone remodeling, muscle atrophy, immune system status, sensorimotor integration, circadian rhythms, and fluid distribution in the body. Current missions are approximately 6 months in length, but preparation for long-duration exploration missions will require additional examination of these physiological changes over longer periods of time. NASA uses microgravity-compatible aspects of remote medicine to enable better diagnosis and treatment of crewmembers, but currently the medical and physiological research systems still rely heavily on return of physiological samples (blood, urine, and saliva) from the ISS to ground laboratories for analysis. NASA is developing additional analytical instrumentation onboard the ISS to improve both diagnostic and research capabilities. To reduce risk to the crewmembers during sample collection as well as to improve crew compliance and participation, NASA is also exploring the expanded use of saliva as a physiological fluid for both clinical tests and research studies.

9112-26, Session 4

Drug stability analyzer for long duration spaceflights

Stuart R. Farquharson, Chetan S. Shende, Real-Time Analyzers, Inc. (United States)

Crewmembers of current and future long duration spaceflights require drugs to overcome the deleterious effects of weightlessness, sickness and injuries. Unfortunately, recent studies have shown that some of the drugs currently used may degrade more rapidly in space, losing their potency before their expiration dates. To complicate matters, the degradation products of some drugs can be toxic. Consequently there is a need for an analyzer that can determine if a drug is safe at the time of use, as well as to monitor and understand space-induced degradation, so that drug types, formulations, and packaging can be improved. Towards this goal we have been investigating the ability of Raman spectroscopy to monitor and quantify drug degradation. Here we present preliminary data by measuring acetaminophen, azithromycin, epinephrine, lidocaine, and their degradation products, as pure samples, commercial products, mixtures, and during forced degradation reactions.

9112-29, Session 4

Non-invasive monitoring of hydration status in warfighters

Sarka O. Southern, Gaia Medical Institute (United States)

No Abstract Available

9112-30, Session 4

Prioritizing military-relevant toxicants and future sensing needs for exposure assessment and adverse health effects *(Invited Paper)*

Jonathan D. Stallings, U.S. Army Ctr. for Environmental Health Research (United States)

No Abstract Available

9112-32, Session 4

Raman spectroscopic analysis of whole sheep's blood acetylcholinesterase

Phillip G. Wilcox, U.S. Army Edgewood Chemical Biological Ctr. (United States) and Johns Hopkins Univ. (United States); Jin U.

Kang, Johns Hopkins Univ. (United States)

Acetylcholinesterase (AChE) is an enzyme used to break down the neurotransmitter acetylcholine. Exposure to organophosphate nerve agents and insecticides can inhibit AChE levels which can lead to a range of physiological responses including restlessness and agitation to seizures, coma, and eventually death. There are currently two main methods used to measure AChE activity, both of which involve drawing a blood sample from a patient, adding reagents observing a chemical reaction over several minutes. A drop in AChE activity levels can indicate OP exposure even before symptoms are present and a quick test without any consumables would allow for more frequent monitoring of AChE activity and could reduce the time between exposure and beginning treatment. In this effort, we examined the ability to use ultraviolet and visible Raman spectroscopy as a rapid and reagentless method to measure AChE activity in whole blood. Raman spectra were taken of whole sheep's blood with varying levels of acetylcholinesterase inhibition using 229 and 532 nm laser excitation wavelengths. AChE levels were inhibited using the organophosphates malathion, paraoxon-ethyl, and octamethyldiphosphoramide and confirmed using the standard Ellman assay. The AChE activity level was assessed with the Raman spectra being analyzed using a partial least squares calibration. Using this technique it was possible to predict a trend in AChE activity using the 229 nm excitation spectra which could potentially be used to trigger a blood draw and more accurate laboratory method.

9112-34, Session 4

Military target task performance after wavefront-guided (WFG) and wavefront-optimized (WFO) photorefractive keratectomy (PRK)

Tana Maurer, Oanh Nguyen, Greg Mueller, Dawne Deaver, Christopher Howell, Steve Moyer, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Denise Ryan, Rose K. Sia, Richard Stutzman, Joseph Pasternak, Kraig Bower, Warfighter Refractive Surgery and Research Ctr. (United States)

Major decisions regarding life and death are routinely made on the modern battlefield, where visual function of the individual soldier can be of critical importance in the decision-making process. Glasses in the combat environment have considerable disadvantages: degradation of visual performance can occur as dust and sweat accumulate on lenses during a mission; visual performance can diminish as lenses become increasingly scratched and pitted; during periods of intense physical trauma, glasses can be knocked off the soldier's face and lost or broken. Although refractive surgery offers certain benefits on the battlefield when compared to wearing glasses, it is not without potential disadvantages. As a byproduct of refractive surgery, elevated optical aberrations can be induced, causing decreases in contrast sensitivity and increases in the symptoms of glare, halos, and starbursts. Typically, these symptoms occur under low light level conditions, the same conditions under which most military operations are initiated. With the advent of wavefront aberrometry, we are now seeing correction not only of myopia and astigmatism but of other, smaller optical aberrations that can cause the above symptoms. In collaboration with the Warfighter Refractive Surgery and Research Center at Fort Belvoir and Walter Reed National Military Medical Center, the overall objective of this study is to determine the impact of wavefront guided (WFG) versus wavefront-optimized (WFO) photorefractive keratectomy (PRK) on military task visual performance. Psychophysical perception testing was conducted before and after surgery to measure each participant's performance regarding target detection and identification using thermal imagery. The results are presented here.

9112-35, Session 4

The challenges of analysing blood stains with hyperspectral imaging

Jaana R. Kuula, Heikki J. Rinta, Hannu-Heikki Puupponen, Ilkka Pölönen, Univ. of Jyväskylä (Finland)

The previous research includes contradictory results of the separation of human blood from other materials with a hyperspectral camera. For the forensic and military medicine the most critical question is whether two different person's blood can be separated with a hyperspectral camera and for which reason this would be possible. According to a previous study, human blood can be separated from some other materials but for example sweet soda may in some occasions cause false interpretations with a hyperspectral camera. However, according to another study, three different persons' and a cow's blood can be separated from each other with a SWIR type of hyperspectral camera. For finding out which results are true in this study the separation of blood is repeated by making even more detailed tests of four persons' blood with NIR, SWIR and MWIR cameras and by analyzing the same blood samples with other kinds of tests as well. The tests try to eliminate factors which might lead into false interpretation of the hyperspectral analysis of blood and to identify some possible ingredients inside the blood which might explain the positive results. Some of those ingredients might not be permanent and due to that reason the hyperspectral image of the same person's blood might not be the same at different times either. The tests are made in cooperation with medical professionals and with forensic investigators.

9112-67, Session 4

NASA laboratory analysis for manned exploration missions

Michael Krihak, Univ. of California, Santa Cruz (United States); Tianna Shaw, NASA Ames Research Ctr., Moffett Field (United States)

No Abstract Available

9112-68, Session 4

Rapid, high-sensitivity diagnostic assay for viral DNA in saliva: translation from space to patients on Earth

Duane L. Pierson, Satish K. Mehta, NASA Johnson Space Ctr. (United States)

No Abstract Available

9112-31, Session Posters-Tuesday

Environmental data and remote sensing as an early warning system for dengue and malaria

Md. Z. Rahman, Kadik Abdel Hamid, LaGuardia Community College (United States); Leonid Roytman, The City College of New York (United States)

Malaria and Dengue fever,the two most common diseases transmitted by mosquitoes, lead to millions of serious illnesses and deaths each year. Because the mosquito vectors are sensitive to environmental conditions such as temperature, precipitation, and humidity, it is possible to map areas currently or imminently at high risk for disease outbreaks using satellite remote sensing. The proposed research intends to develop the first operational geospatial early warning system for malaria and dengue by bringing together geographic information system (GIS) tools, artificial neural networks (ANN) for efficient pattern recognition, the best available ground-based epidemiological and vector ecology data, and current satellite remote sensing capabilities.

We use Vegetation Health Indices (VHI) derived from visible and infrared radiances measured by satellite-mounted Advanced Very High Resolution Radiometers (AVHRR) and available weekly at 4-km resolution as one predictor of malaria and dengue fever risk in Bangladesh. We focus on Bangladesh as an area of study where malaria and dengue fever are serious public health threats. The technology developed however, will be largely portable to other countries in the world and will be applicable to other disease threats. The malaria and dengue fever early warning system will be a boon to international public health by enabling resources to be focused where they will do the most good to stop pandemics, and will be an invaluable decision support tool for national security assessments regarding potential troop deployment in regions susceptible to disease outbreaks.

9112-49, Session Posters-Tuesday

Simulation studies in biochemical signaling and enzyme reactions

Mary C. Vagula, Gannon Univ. (United States); Sudarshan R. Nelatury, Penn State Erie, The Behrend College (United States); Charles F. Nelatury, Drexel Univ. (United States)

Biochemical pathways characterize various biochemical reaction schemes that involve a set of species and the manner in which they are connected. Determination of schematics that represent these pathways is an important task in understanding metabolism and signal transduction. Examples of these

Pathways are: DNA and protein synthesis, and production of several macro-molecules essential for cell survival. A sustained feedback mechanism arises in gene expression and production of mRNA that lead to protein synthesis if the protein so synthesized serves as a transcription factor and becomes a repressor of the gene expression. The cellular regulations are carried out through biochemical networks consisting of reactions and regulatory proteins.

Systems biology is a relatively new area that attempts to describe the biochemical pathways analytically and develop reliable mathematical models for the pathways. A complete understanding of chemical reaction kinetics is prohibitively hard thanks to the nonlinear and highly complex mechanisms that regulate protein formation, but attempting to numerically solve some of the governing differential equations seems to offer significant insight about their biochemical picture. To validate these models, one can perform simple experiments in the lab.

This paper proposes some simulation studies and presents interesting results in enzyme parameter estimation. MATALB software is used to write the script and to obtain numerical solutions. The statistical technique used is non-linear regression. Also we wish to look into certain oscillatory mechanisms by solving differential equations of Elowitz and Leibler.

9112-50, Session Posters-Tuesday

Health hazards of radio wave frequency radiation on gene expression during early embryonic development using zebra fish

Mary C. Vagula, Ryan Harkless, Muntather Alquraishi, Gannon Univ. (United States)

With the reality of increasing and unavoidable exposure to radio-wave frequency (RF) radiation, it is imperative that the effects of such radiation on living organisms be well understood. In particular, it is critical to understand any effects that RF radiation may have on gene expression during embryonic development, as this is a crucial and delicate time for any organism. Proper understanding of the genes that are expressed during this time is very important. Owing to any effects that RF radiation may have on gene expression, it is essential to understand any carcinogenic or teratogenic properties that it may show. As a model organism, zebra fish (Danio rerio) have been studied extensively, and their value in studies of gene expression cannot be overstated. This study will observe the effects of RF radiation emitted from a cellular telephone on the embryonic development of zebra fish. The expression of two genes, shha and hoxB9a, that are key to the early development of the fish will be examined; both genes have homologs in humans as well as in other model organisms. The goal of this study is to provide data on the expression of these two genes during early embryonic development in D. rerio and any effects that cell phone radiation has on them.

9112-51, Session Posters-Tuesday

Remote laser spectroscopy of oil and gas deposits

Sergey V. Kascheev, National Research Univ. of Information Technologies, Mechanics and Optics (Russian Federation)

Raman lidar with spectral resolution of $\lambda/\Delta\lambda > 1000$ mounted on helicopter board have been demonstrated in prospecting of methane leaks on transcontinental pipe. Such ultraspectral resolution allows to eliminate the spectral lines overlap under significant difference of gas concentrations in the atmosphere.

Laser remote spectroscopy availability for airborne search of the oil-and-gas deposits has been examined. Essential reduction of terms and economic expenses for search of new hydrocarbonic deposits is reached by complex carrying out of laser sensing, geological and seismic survey. The heavy hydrocarbon gases (HHG) are the oil-gas deposits indicator agents.

Experiments were carried out under the CARS circuit. Hermetic chamber filled by mixture of such gases and air served as the simulator of hydrocarbon halo was irradiated by Ti:Saphire and Nd:YAG lasers. Thus pulses of femtosecond (λ = 800 nm) and nanosecond (λ = 1064 nm) duration were focused in a chamber. Spectra were registered with use of the EPP200 compact optical fiber spectrometer. Back scattering anti-Stocks radiation got on a spectrometer and received spectrum was further processed on a computer. Pressure of methane and propane chosen as indicator substances of hydrocarbon deposits was made ~ 0.01 Torr in 0.2 m-length chamber that was corresponded to 10m-thickness of an real halo with concentration at level of 5•1012 sm-3, i.e. 200 ppb, for each of these gases. Since the Ti:Saphire laser has a wide spectrum, the coherent anti-Stock scattering of radiation occurs from corresponding Fourier-components of pump (λ = 800 nm) and Stocks signal (λ = 1064 nm), removed on Stocks shift size of researched gases from ND:YAG laser wavelength. Therefore it was possible to observe an occurrence of new components about 650 nm, various for different HHG (fig.1), in anti-Stock scattering spectrum.

As estimations have shown the reliability of HHG detection can exceed 80 % at the integration method of seismic prospecting and laser remote sensing in CARS circuit with the use of Nd:YAG laser (1064 nm, 3J, 6 ns, 300 Hz)

9112-52, Session Posters-Tuesday

Investigation of plasmonic enhancement of chlorophyll emission in optical waveguide for algae detection

Jimmy Wang, National Sun Yat-Sen Univ. (Taiwan)

This study aims to integrate lately development of Plasmonic enhancement of nano-metal with optical fiber technology; manly to exploit fiber technology from telecommunication to sensing applications. Although the optical fiber technology in telecommunication is quite mature, there are still quite a lot research and development have to be done in order to enable its practical utilization in great extent.

In this paper, we like to address the followings:

(1) Fabrication of nano-silver incorporated fiber probe: two main issues are loss and nano-silver distribution in optical fiber waveguide.

(2) Plasmon-enhancement effectiveness of silver on chlorophyll photoemission: the main interest is to study the extent of enhancement

factor and mechanism as function of spectra overlap between silver's emission and chlorophyll's absorption.

(3) Exploiting the fiber probe with optimal Plasmon-enhancement design for algae detection and making a comparison to current products.

9112-53, Session Posters-Tuesday

Analysis of a generalized model for influenza including differential susceptibility due to immunosuppression

Juan F. Ospina, Univ. EAFIT (Colombia)

Recently, a mathematical model of pandemic influenza was proposed including typical control strategies such as antivirals, vaccination and school closure; and considering explicitly the effects of immunity acquired from the early outbreaks on the ulterior outbreaks of the disease. In such model the algebraic expression for the basic reproduction number (without control strategies) and the effective reproduction number (with control strategies) were derived and numerically estimated. A drawback of this model of pandemic influenza is that it ignores the effects of the differential susceptibility due to immunosuppression and the effects of the complexity of the actual contact networks between individuals. We have developed a generalized model which includes such effects of heterogeneity. Specifically we consider the influence of the air network connectivity in the spread of pandemic influenza and the influence of the immunosuppression when the population is divided in two immune classes. We use an algebraic expression, namely the Tutte polynomial, to characterize the complexity of the contact network. Until now, The influence of the air network connectivity in the spread of pandemic influenza has been studied numerically, but not algebraic expressions have been used to summarize the level of network complexity. The generalized model proposed here includes the typical control strategies previously mentioned (antivirals, vaccination and school closure) combined with restrictions on travel. For the generalized model the corresponding reproduction numbers will be algebraically computed and the effect of the contact network will be established in terms of the Tutte polynomial of the network.

9112-54, Session Posters-Tuesday

Using computer algebra and SMT-solvers to analyse a mathematical model of cholera transmission

Mariana Trujillo Arredondo, Univ. EAFIT (Colombia)

We analyze a mathematical model for the transmission of cholera. The model is already defined and involves variables such as the pathogen agent, which in this case is the bacterium Vibrio cholera, and the human population. The human population is divided into three classes: susceptible, infectious and removed. Using Computer Algebra, specifically Maple we obtain two equilibrium states: the disease free state and the endemic state. Using Maple it is possible to prove that the disease free state is locally asymptotically stable if and only if $R0 < 1$. Using Maple it is possible to prove that the endemic equilibrium state is locally stable when it exists, it is to say when $R0 > 1$.

Using the package Red-Log of the Computer algebra system Reduce and the SMT-Solver Z3Py it is possible to obtain numerical conditions for the model. The formula for the basic reproductive number makes a synthesis with all epidemic parameters in the model. Also it is possible to make numerical simulations which are very illustrative about the epidemic patters that are expected to be observed in real situations. We claim that these kinds of software are very useful in the analysis of epidemic models given that the symbolic computation provides algebraic formulas for the basic reproductive number and such algebraic formulas are very useful to derive control measures. For other side, computer algebra software is a powerful tool to make the stability analysis for epidemic models given that the all steps in the stability analysis can be made automatically: finding the equilibrium points, computing the jacobian, computing the characteristic polynomial for the jacobian, and applying the Routh-Hurwitz theorem to the characteristic polynomial. Finally, using SMT-Solvers is possible to make automatically checks of satisfiability, validity and quantifiers elimination being these computations very useful to analyse complicated epidemic models.

9112-55, Session Posters-Tuesday

Computational algebraic geometry of epidemic models

Martin Rodriguez, Univ. EAFIT (Colombia)

Computational Algebraic Geometry is applied to the analysis of various epidemic models for Schistosomiasis and Dengue, both, for the case without control measures and for the case where control measures are applied. The models were analyzed using the mathematical software Maple. Explicitly the analysis is performed using Groebner basis, Hilbert dimension and Hilbert polynomials. These computational tools are included automatically in Maple. Each of these models is represented by a system of ordinary differential equations, and for each model the basic reproductive number (R_0) is calculated. The effects of the control measures are observed by the changes in the algebraic structure of R_0, the changes in Groebner basis, the changes in Hilbert dimension, and the changes in Hilbert polynomials. It is hoped that the results obtained in this paper become of importance for designing control measures against the epidemic diseases described. For future researches it is proposed the use of algebraic epidemiology to analyze models for airborne and waterborne diseases.

9112-56, Session Posters-Tuesday

Using Tutte polynomials to characterize sexual contact networks

Juan José Cadavid Muñoz, Univ. EAFIT (Colombia)

Tutte polynomials are used to characterize the dynamic and topology of the sexual contact networks, in which pathogens are transmitted as an epidemic. Tutte polynomials provide an algebraic characterization of the sexual contact networks and allow the projection of spread control strategies for sexual transmission diseases. With the usage of Tutte polynomials, it allows obtaining algebraic expressions for the basic reproductive number of different pathogenic agents. Computations are done using the computer algebra software Maple, and it's GraphTheory Package. The topological complexity of a contact network is represented by the algebraic complexity of the correspondent polynomial. The change in the topology of the contact network is represented as a change in the algebraic form of the associated polynomial. With the usage of the Tutte polynomials, the number of spanning trees for each contact network can be obtained. From the obtained results in the polynomial form, it can be said that Tutte polynomials are of great importance for designing and implementing control measures for slowing down the propagation of sexual transmitted pathologies. As a future research line, the analysis of weighted sexual contact networks using weighted Tutte polynomials is considered.

9112-57, Session Posters-Tuesday

Computing Ro in a population with heterogeneity in sexual activity and proportionate mixing using a STM-solver

Natalia A. Gutierrez, Univ. EAFIT (Colombia)

A model to determinate the reproductive basic number, detonated Ro, for the case of population with heterogeneity in sexual activity and proportionate mixing is solved using computer algebra and SMT solvers. Specifically Maple and Z3 were used. The code for the solution of the

model was written in Z3-Python, but it can also be played by Z3-SMT-Lib. R0 represents an algebraic synthesis of every epidemiological parameter. Numerical simulations were done to prove the effectiveness of the model and the code. The algebraic structure of R0 suggests the possible control measurements that should be implemented to avoid the propagation of the sexual transmitted diseases. The obtained results are important on the computational epidemiology field. As a future investigation, it is suggested to apply the STM solvers to analyze models for other kinds of epidemic diseases.

9112-58, Session Posters-Tuesday

Bessel filters applied in biomedical image processing

Juan P. Mesa Lopez, Univ. EAFIT (Colombia)

A magnetic resonance is an image obtained by means of an imaging test that uses magnets and radio waves to create body images, however, in some images it's difficult to recognize organs or foreign agents present in the body. With these Bessel filters the objective is to significantly increase the resolution of magnetic resonance images taken to make them much clearer in order to detect anomalies and diagnose the illness. As it's known, Bessel filters appear to solve the Schrödinger equation for a particle enclosed in a cylinder and affect the image distorting the colors and contours of it, therein lies the effectiveness of these filters, since the clear outline shows more defined and easy to recognize abnormalities inside the body.

9112-59, Session Posters-Tuesday

Application of a Morse filter in the processing of a brain angiogram

Santiago Venegas Bayona, Univ. EAFIT (Colombia)

The angiograms are frequently used to find anomalies in the blood vessels. Hence, for improving the quality of the images with an angiogram, a Morse filter will be implemented (based on the model of the Morse Potential) in a brain's vessels angiogram using both softwares Maple ® and ImageJ ®.

It will be shown the results of applying a Morse filter to an angiogram of the brain vessels. First, the image was processed with ImageJ using the plug-in Anisotropic Diffusion 2D and then, the filter was implemented.

As it is illustrated in the results, the edges of the stringy elements are emphasized. Particularly, this is very useful in the medical image processing of blood vessels, like angiograms, due to the narrowing or obstruction which may be caused by illness like aneurysms, thrombosis or other diseases.

9112-60, Session Posters-Tuesday

Using special functions to model the propagation of airborne diseases

Daniela D. B. M. Bolaños Marin, Univ. EAFIT (Colombia)

Some special functions of the mathematical physics are using to obtain a mathematical model of the propagation of airborne diseases. In particular we study the propagation of tuberculosis in closed rooms and we model the propagation using the error function and the Bessel function. In the model, infected individual emit pathogens to the environment and this infect others individuals who absorb it.

The evolution in time of the concentration of pathogens in the environment is computed in terms of error functions. The evolution in time of the number of susceptible individuals is expressed by a differential equation that contains the error function and it is solved numerically for different parametric simulations. The evolution in time of the number of infected individuals is plotted for each numerical simulation. On the other hand, the spatial distribution of the pathogen around the source of infection is represented by the Bessel function K0.

The spatial and temporal distribution of the number of infected individuals is computed and plotted for some numerical simulations. All computations were made using software Computer algebra, specifically Maple.

It is expected that the analytical results that we obtained allow the design of treatment rooms and ventilation systems that reduce the risk of spread of tuberculosis.

9112-61, Session Posters-Tuesday

Optimal control in a model of malaria with differential susceptibility

Isabel Montoya Arroyave, Juan F. Ospina, Univ. EAFIT (Colombia)

A malaria model with differential susceptibility is analyzed using the optimal control technique. In the model the human population is classified as susceptible, infected and recovered. Susceptibility is assumed dependent on genetic, physiological, or social characteristics that vary between individuals. The model is described by a system of differential equations that relate the human and vector populations, so that the infection is transmitted to humans by vectors, and the infection is transmitted to vectors by humans. The model considered is analyzed using the optimal control method when the control is the use of insecticide-treated nets, and the optimality criterion is to minimize the number of infectious humans, while keeping the cost as low as possible. It is determine the effects of differential susceptibility in the proposed control mechanism and it is determine the algebraic form of the basic reproductive number of the model. All computations are performed using computer algebra, specifically Maple. It is claimed that the analytical results obtained are important for the design and implementation of control measures of malaria. It is suggested some future investigations as the application of the method to other vector-borne diseases such as dengue or yellow fever, and is suggested the possible application of free software of computer algebra like Maxima.

9112-62, Session Posters-Tuesday

Using quantum filters to process images of diffuse axonal injury

Mateo Pineda Osorio, Univ. EAFIT (Colombia)

Some images corresponding to a diffuse axonal injury (DAI) are processed using several quantum filters such as Hermite, Bessel and Morse. Diffuse axonal injury is a particular, common and severe case of traumatic brain injury (TBI). DAI involves global damage on microscopic scale of brain tissue and causes serious neurologic abnormalities. New imaging techniques provide excellent images showing cellular damages related to DAI. Said images can be processed with quantum filters, which accomplish high resolutions of dendritic and axonal structures both in normal and pathological state. Using the Laplacian operators from the new quantum filters, excellent edge detectors for neurofiber resolution are obtained. Image quantum processing of DAI images is made using computer algebra, specifically Maple. Quantum filter plugins construction is proposed as a future research line, which can incorporated to the ImageJ software package, making its use simpler for medical personnel.

9112-36, Session 5

Next generation disease diagnostics: advances in laboratory and field-expedient technologies *(Invited Paper)*

Stephen M. Hewitt, National Cancer Institute (United States)

No Abstract Available

9112-70, Session 5

Current NIH funding opportunities in optical imaging and spectroscopy *(Invited Paper)*

Richard Conroy, National Institutes of Health (United States)

The National Institutes of Health (NIH) is the largest funder of biomedical research in the world, supporting thousands of research projects and scientists. One of the 27 Institutes and Centers that comprise NIH has the specific mission to support biomedical imaging and bioengineering, though many of the other Institutes have significant programs in these areas. NIBIB has an annual budget of ~$330 million and the five goals of: 1) supporting development of innovative biomedical technologies, 2) enabling patient-centered health care, 3) advancing our understanding of cellular and molecular disease processes, 4) developing accessible medical technologies and 5) training the next generation of interdisciplinary researchers. This presentation will give an overview of some of the current work being funded by NIBIB, some of the current funding opportunities available at NIBIB, as well as highlighting some of the trans-NIH initiatives including Big Data to Knowledge and BRAIN. Special attention will be given to opportunities that are relevant to the optical imaging and spectroscopy community.

9112-74, Session 5

Quantification of cellular disease biomarkers using digital image analysis

James Evans, Gaia Medical Institute (United States)

No Abstract Available

9112-75, Session 5

Saliva-based multiplex technology: applications for oral clinical diagnostics in HIV/AIDS

Jennifer Webster-Cyriaque, The Univ. of North Carolina at Chapel Hill (United States)

No Abstract Available

9112-38, Session 6

Portable capillary electrophoresis-system for on-site food analysis with lab-on-a-chip based contactless conductivity detection *(Invited Paper)*

Claudia Gärtner, René Sewart, Richard Klemm, Holger Becker, microfluidic ChipShop GmbH (Germany)

A portable analytical system for the characterization of liquid environmental samples and beverages in food control was realized. The key element is the implementation of contactless conductivity detection on lab-on-a-chip basis ensuring the system to be operated in a label free mode without any necessity of analyte staining.

While chip-based capillary electrophoresis has established itself as one of the fastest and potentially convenient methods for the analysis of larger molecules in many biotechnological and clinical applications, the large and economically attractive field of analysis of foodstuff and environmental screening has not been addressed with the same intensity. This is the more surprising, as increased regulatory requirements, the commercial structure of the food industry and the inherent perishable nature of the ingredients make this field an ideal candidate for a small and fast analysis system which can be operated on-site at the food production site.

A fully integrated chip-based capillary electrophoresis device realized as compact portable chip-based capillary electrophoresis system employing capacitively coupled contactless conductivity detection (C4D) as an alternative detection method compared to the commonly used optical detection based on laser-induced fluorescence will be introduced. Typical target molecules such as small ionic species like Li+, Na+, K+, SO42- or NO3-, organic acids in wine whose concentration and ratio to each other documents the wine quality, or caffeine or phosphate in coke were detected. Results from sample matrices like various beverages as water, coke, tea, wine and milk, water from heaters, environmental samples and blood will be presented.

The instrument, the lab-on-a-chip as consumable, and the application and protocols established on the system will be highlighted. Fast analysis times of a few minutes to seconds, detection limits in the µM range, and the realization as portable system offers the system itself as ideal tool for on-site analytical tasks.

9112-39, Session 6

Critical stages of a biodetection platform development from sensor chip fabrication to surface chemistry and assay development

Yildiz Uludag, TUBITAK UME (Turkey)

Once viewed solely as a tool to analyse biomolecular interactions, biosensors are gaining widespread interest for diagnostics, biological defense, environmental and quality assurance in agriculture/food industries. Advanced micro fabrication techniques have facilitated integration of microfluidics with sensing functionalities on the same chip making system automation more convenient. Biosensor devices relying on lab-on-a-chip technologies and nanotechnology has attracted much of attention in recent years for biological defense research and development. However, compared with the numerous publications and patents available, the commercialization of biosensors technology has significantly lagged behind the research output. This presentation reviews the reasons behind the slow commercialisation of biosensors with an insight to the critical stages of a biosensor development from the sensor chip fabrication to surface chemistry applications and nanotechnology applications in sensing with case studies.

In addition, the presentation will include the description of a new biodetection platform based on Real-time Electrochemical Profiling (REP) that comprises novel electrode arrays and nanoparticle based sensing. The performance of the REP platform has been tested for the detection of Planktothrix agardhii, one of the toxic bloom-forming cyanobacteria, usually found in shallow fresh water sources that can be used for human consumption. The optimised REP assay allowed the detection of P. agardhii DNA down to 6 pM. This study, showed the potential of REP as a new biodetection platform for toxic bacteria and hence further studies will involve the development of a portable multi-analyte biosensor based on REP technology for on-site testing.

9112-40, Session 6

Chemoselective surface attachment of antimicrobial peptides and its effects on interfacial behavior

Stella H. North, Christopher So, Kenan Fears, Chris R. Taitt, U.S. Naval Research Lab. (United States)

Protein and peptide-based biological recognition elements are valuable agents for biosensors used for biodefense systems. The utilization of such biomolecules for detection purposes relies on the ability to immobilize them on the surface of a detection platform in a predictable and reliable manner that facilitates target binding. Numerous immobilization methods have been used to improve the performance of protein and peptide-based biosensors and strategies; however, the molecular details of how surface attachment affects structure and activity require further investigation to

establish general approaches for obtaining consistent sensor surfaces. This has been largely due to the lack of analytical techniques. Using surface infrared and circular dichroic spectroscopies, we examined the orientation and secondary structure of peptide tethered to solid support. Different tethering parameters were investigated by substituting a cysteine residue to the N-terminus, C-terminus, or at two central points in cationic antimicrobial peptides, and its effects on antimicrobial activity against gram-positive and gram-negative bacteria. Spectroscopic analyses showed that surface immobilization may drive transition of peptides secondary structures, resulting in different interfacial behaviors. We have begun to gain insight into how surface attachment may have direct implications for peptide presentation and function and is an important advance in preparing a robust sensing interface.

9112-41, Session 6

Data-driven classification of HEp-2 immunofluorescence patterns for autoimmune disease diagnosis

Victor V. Pomponiu, Harishwaran Hariharan, Univ. of Pittsburgh (United States)

Currently, the Indirect Immunofluorescence (IIF) technique is widely used to identify infections that affect the human autoimmune system. Essentially, the approach consists in the examination of the patient serum in order to find antinuclear autoantibodies (ANAs). However, it is a subjective method that hinges on the experience and expertise of the physician. Therefore, devising an accurate computer aided classification system is of great importance for the detection of autoimmune infections. In this paper, we present a novel method for automatic classification of the staining patterns of IIF cell images. To achieve this objective, we combine a robust and scalable multi-class classifier with several discriminative visual features extracted from a set of images obtained through a multiresolutional decomposition based on bilateral filtering. The feature set comprises the co-occurrence local binary patterns (coLBP), used to characterize the textural structure of the HEp-2 cell images, along with several statistical measures such as area, eccentricity, mean, standard deviation, entropy and contrast. After the features are computed, a k nearest neighbor (NN) classifier, with a similarity measure as distance, is used to perform the classification. In this study the capability of the method is assessed on a large dataset comprising 13596 cell images pertaining to six most frequently occurred strain classes, i.e., homogeneous, centromere, speckled, nucleolar, numem, and golgi. The result computed with 5 fold cross validation shows the feasibility and clinical efficiency of our automated classification system.

9112-42, Session 6

Automated detection of pulmonary emphysema in CT images of the lungs

Victor V. Pomponiu, Harishwaran Hariharan, Univ. of Pittsburgh (United States)

Visual assessment and the relative area of voxels below a specific threshold (RA) are the common methods used to examine chronic obstructive pulmonary diseases (COPD), such as bronchitis and emphysema, in computed tomography (CT) images. However these approaches are subjective, lack automation and their performances depends on the radiologist experience. Computerized evaluation of pulmonary CT images has emerged as an alternative that can efficiently assess the two constituents of COPD. In this study we investigate the use of complete local binary patterns (CLBP) and Webber local descriptor (WLD) as joint histogram features in a classification framework which aims to characterize the textural patterns in CT images. The classification is carried out using the support vector machines (SVMs) with a radial base function as the kernel. The proposed texture-based scheme is tested on the CT emphysema database which contains a set of 168 regions of interest (ROIs) including various emphysema patterns and normal tissue, and compared to RA and Gaussian-based filter bank. The joint CLBP and WLD feature set, which achieves a classification accuracy of 90.1%, shows superior performance than of those previously reported in the literature.

9112-43, Session 6

Software system for computing material and structural properties of bone and muscle in the lower extremity from PQCT

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Peripheral Quantitative Computed Tomography (pQCT) imaging technology facilitates the non-invasive assessment of material, structural and functional properties of the peripheral human skeleton using low radiation doses. Herein we present a software system for hard and soft tissue quantification in the lower leg with encouraging accuracy and precision using pQCT imaging data. Our interest is focused on segmentation and identification of bone, muscle and fat regions which are key components for the computation of densitometric and geometric variables of each regional tissue type. The computed material parameters are mineral density averages and standard deviations, and the structural parameters are areas and principal moments for each tissue type. We validated our method against reference area and densitometric measurements over a set of test images at three tibia sites (proximal, medial, distal). Reference measurements were produced by a clinical specialist who executed a supervised image analysis workflow. Linear regression model parameters and squared correlation coefficient (R-squared) values measure the agreement level between the two methods. Validation shows very good agreement with reference material and structural variables of muscle and bone. The R-squared values between the automated and semi-manual method for muscle area and density are 0.997 and 0.85 (N=12). The corresponding R-squared values for cortical bone area and density are 0.85 and 0.72 respectively (N=27). Another advantage of this method is that it is highly reproducible because manual operations have been minimized. Finally, its software design allows installation on different computer platforms and frontends (i.e., standalone console application, or plug-in GUI component).

9112-44, Session 6

Label-free single cancer marker protein detection using a nanoplasmonic-photonic hybrid whispering gallery mode biosensor

Stephen Holler, Fordham Univ. (United States); Venkata R. Dantham, Curtis Barbre, David Keng, Polytechnic Institute of New York Univ. (United States); Vasily Kolchenko, New York City College of Technology (United States); Stephen Arnold, Polytechnic Institute of New York Univ. (United States)

The growth of tumors within the body often leads to the presence or elevated level of protein markers within bodily fluids. These protein markers circulate throughout the body and may serve as indicators that warn of early stage infection or the reemergence of the disease; a canary of sorts, provided one can detect their presence. We recently reported label-free single protein detection using a nanoplasmonic-photonic hybrid resonant microcavity. Plasmonic-enhanced resonant systems have proven effective at being highly sensitive and highly responsive to changes in their environment. While small single viruses have been detected with a plasmonic-photonic hybrid whispering gallery mode sensor, individual proteins have remained beyond the limits of detection. This limitation was largely imposed by the assumed morphology of the plasmonic nanoparticle; a smooth sphere. In reality, the plasmonic nanoparticles have textured surfaces with peaks, valleys and regions of high curvature. As a result, the electric field in the vicinity of a plasmon resonance may be considerably

higher in this rough morphology than in the smooth surface case. This realization has led us to be able to detect the binding of individual protein markers to the surface of the hybrid resonator. The enhanced detection capability was demonstrated using small protein molecules (BSA (66 kDa) and Tg (660 kDa)), which resulted in the observation of a larger (2.4? - 15?) response than expected from this smooth surface model and allows us to project the limit of detection of the whispering gallery mode sensor to be 5 kDa.

9112-45, Session 6

Miniature polymer Fabry-Perot sensor with dual optical cavities for simultaneous pressure and temperature measurements

Hyungdae Bae, Miao Yu, Univ. of Maryland, College Park (United States)

We present a miniature polymer Fabry-Perot sensor fabricated at the tip of an optical fiber for simultaneous pressure and temperature measurements. The pressure sensing cavity is an extrinsic air cavity created on a polymer housing by using an optically aligned UV-molding process. A metal/polymer composite diaphragm is exploited as the pressure transducer for achieving a high pressure sensitivity while maintaining a miniature sensor size. Another intrinsic polymer cavity is used for temperature sensing. The added polymer layer makes it possible to achieve a high temperature sensitivity with a short cavity length due to the large thermal expansion of the polymer (~ 90 times larger). The overall sensor size is around 150 μm in diameter and 120 μm in length. Experimental study shows that the sensor exhibits a good linearity over a pressure range of 1 psi to 5 psi with a pressure sensitivity of 0.010 μm/kPa at 26°C, and a temperature range of 26.0 °C to 50.0 °C with a temperature sensitivity of 0.006 μm/°C. An optical signal processing method is developed to retrieve the two cavity length changes, which is demonstrated to have a better resolution and a faster speed than the conventional method. The sensor is expected to benefit many fronts that require simultaneous pressure and temperature measurements with minimum intrusiveness, especially for biomedical applications due to its small size and high pressure and temperature sensitivities.

9112-46, Session 6

Prototype spectral analysis of water samples for monitoring and treatment of public water resources *(Invited Paper)*

Samuel G. Lambrakos, Maria Lee, U.S. Naval Research Lab. (United States); Constantine Yapijakis, The Cooper Union for the Advancement of Science and Art (United States); Scott A. Ramsey, Lulu Huang, U.S. Naval Research Lab. (United States); Andrew Shabaev, George Mason Univ. (United States); Lou Massa, Hunter College (United States)

Experimental measurements conducted in the laboratory, involving hyperspectral analysis of water samples taken from public water resources in the New York City metro area, have motivated a reevaluation of issues concerning the potential application of this type of analysis for water monitoring, treatment and evaluation prior to filtration. One issue concerns hyperspectral monitoring of contaminants with respect to types and relative concentrations. This implies a need for better understanding the statistical profiles of water contaminants in terms of spatial-temporal distributions of electromagnetic absorption spectra ranging from the ultraviolet to infrared, which are associated with specific water resources. This issue also implies the need for establishing correlations between hyperspectral signatures and types of contaminants to be found within specific water resources. Another issue concerns the use of absorption spectra for determining changes in chemical and physical characteristics of contaminants after application of water treatments in order to determine levels of toxicity with respect to the environment.

9112-47, Session 6

Estimation of suspended sediment concentrations by spectral reflectance: a field survey on the Yellow River *(Invited Paper)*

Liqin Qu, Xiusheng Yang, Daniel Civco, Univ. of Connecticut (United States)

The dynamic sediment distribution on the large river with dams constructed often attract wide attention due to their possible adverse environmental impacts. Sediment transportation modeling and accurate evaluation of environmental effects are often hindered by the lack of sediment measurements with spatial details. This study aimed to investigate the method to estimate the suspended sediment concentrations (SSCs) from on-site spectral measurements. The study investigated the spectral signature of river water between natural channel and Sanmenxia reservoir on the Yellow River. A field spectral survey was conducted with on-site spectral and SSCs measured by spectroradiometer and sampling of water. The result confirmed an exponential relationship between SSC and reflectance that was reported in the previous study on a tank experiment. A single band model (R = 0.8, RMS E = 0.28g/l) was built for estimate SSC using band setting same as the band 4 of Landsat 7 image (760nm-900nm). We also apply the Spectral Mixing Algorithm(SMA) from the tank experiment to the on-site spectral measurements. The result shows the SMA models were better than single band model, but the improvement was not very significant. This study could provide critical instructional assistance for estimating SSC directly from remote sensing data.

9112-48, Session 6

Antarctic sea ice temperature monitoring using passive microwave SSM/I data

Liu Yanxia, Wuhan Univ. (China)

Sea ice is a significant indicator of global climate change, and sea ice temperature is one of the most important factors for sea ice observation. Passive microwave remote sensing technology is seldom susceptible to the impact of clouds and has certain advantages for the special climatic environment of polar regions. Sea ice temperature was inverted using each month of 2003-2011 Southern Hemisphere SSM/I data based on radiation transfer iteration algorithm in this paper. The validity of results was verified by sea ice temperature derived from AMSR-E, and results of Great Wall Station and Zhongshan Station were analyzed, the result presents high retrieval precision and a consistent trend compared with the past climate change.

9113-1, Session 1

The effects of gamma irradiation on micro-hotplates with integrated temperature sensing diodes *(Invited Paper)*

Laurent A. Francis, Nicolas André, Pierre Gérard, Univ. Catholique de Louvain (Belgium); Zeeshan Ali, Florin Udrea, Cambridge CMOS Sensors (United Kingdom); Denis Flandre, Univ. Catholique de Louvain (Belgium)

Micro-hotplates are MEMS structures of interest for low-power gas sensing, lab-on-chips and space applications, such as micro-thrusters. Micro-hotplates usually consist in a Joule heater suspended on a thin-film membrane while thermopiles or thermodiodes are added as temperature sensors and for feedback control. The implementation of micro-hotplates using a Silicon-On-Insulator technology makes them suited for co-integration with analog integrated circuits and operation at elevated environmental temperatures in a range from 200 to 300 °C, while the heater allows thermal cycling in the kHz regime up to 700 °C, e.g. necessary for the activation of gas sensitive metal-oxide on top of the membrane, with mW-range electrical power. The demonstrated resistance of micro-hotplates to gamma radiations can extend their use in nuclear plants, biomedical sterilization and space applications.

In this work, we present results from electrical tests on micro-hotplates during their irradiation by Cobalt-60 gamma-rays with total doses up to 20 kGy. The micro-hotplates are fabricated using a commercial 1.0 µm Silicon-On-Insulator technology with a Tungsten Joule heater, which allows power-controlled operation above 600 °C with less than 60 mW, and temperature sensing silicon diodes located on the membrane and on the bulk. We show the immunity of the sensing platform to the harsh radiation environment. Beside the good tolerance of the thermodiodes and the membrane materials to the total radiation dose, the thermodiode located on the heating membrane is constantly annealed during irradiation and keeps a constant sensitivity while the thermodiode located in the bulk can be restored entirely by post-irradiation annealing.

9113-2, Session 1

AlN-based resistive random access memory for harsh environment

Po-Kang Yang, National Taiwan Univ. (Taiwan)

An AlN-based resistive random access memory (RRAM) device with transmittance above 80%, (On/Off) ratio over than 10, and radiation hardness is demonstrated. The operation voltages (reset & set voltages) are within ±3 V, and multilevel storage capabilities can be achieved by current compliance modification. Moreover, the AlN-based RRAM device can be operated under the proton irradiation fluences to up 1015 cm-2, showing it potential for harsh electronics due to their superior stability under radiation bombardment. The obtained results presented could not only be a fundamental for see-through electronic devices, but also for harsh environment.

9113-3, Session 1

Effects of radiation and temperature on gallium nitride (GaN) metal-semiconductor-metal ultraviolet photodetectors

Heather Chiamori, Minmin Hou, Debbie G. Senesky, Stanford Univ. (United States)

Ultraviolet (UV) radiation photodetectors are often used in extreme harsh environment applications such as flame detection, imaging, space navigation and astronomy. For applications such as sun sensors, where UV light from the sun is used to determine spacecraft attitude and altitude as well as orientation in deep space, the detectors may be exposed to both ionizing radiation and extreme temperature swings. UV photodetectors based on gallium nitride (GaN) materials are an attractive option. With a wide bandgap of 3.4 eV, advantages of GaN-based materials include direct bandgap for better spectral selectivity, cutoff wavelength selection based on ternary alloy mole fraction, high current density, thermal stability, and radiation hardness. To determine the robustness of GaN-based UV photodetectors in extreme harsh environments, the effects of ionizing radiation and temperature excursions are examined. The initial materials platform is thin film GaN-on-sapphire substrates. UV photodetectors in a metal-semiconductor-metal (MSM) configuration are fabricated on the GaN substrates, exposed to a total ionizing dose of 100 krad from a Cs-137 source with no shielding (J.L. Shepherd and Associates) and annealed per military specifications. The photoresponse of irradiated detectors is compared with control samples. Additionally, samples are exposed to various temperature ranges to evaluate detector performance with and without exposure to harsh environmental conditions. Several materials for the photodetector anode and cathode are also evaluated.

9113-5, Session 2

Silicon carbide solid-state photomultiplier for UV light detection

Stanislav Soloviev, Peter Sandvik, Sabarni Palit, Sergei Dolinsky, GE Global Research (United States)

The detection of signals with high signal-to-noise in the deep UV wavelength range is desired for various applications, including flame detection, biological and chemical detection, as well as for the detection of jet engines and missile plumes. For detection of low photon flux, solid-state photomultipliers (SSPMs) may offer advantages compared to conventional photomultiplier tubes, including lower supply voltages, smaller volume and greater robustness. Due to its wide bandgap, silicon carbide (SiC) is a suitable material for UV detection at elevated temperatures. Here, we report on the design and fabrication of SiC-based SSPMs for detection of faint UV light.

The SiC SSPM consists of an array of individual SiC APDs connected in parallel. Each individual APD (pixel) has its own quenching resistor connected in series. Unlike silicon, modern SiC substrates have structural defects such as basal plane and threading dislocations. It has been shown that these defects are responsible for higher leakage currents in APDs operating in linear mode or for higher dark count rates in APDs operating in Geiger mode. In this work, in order to minimize the impact of the structural defects on device performance, the diameter of the APD pixels was optimized based on empirical correlation between the number of defects per device and the dark count rate of SiC devices. Device design parameters as well as optical and electrical performance will be presented

9113-6, Session 2

4H-SiC PN diode for extreme environment temperature sensing applications

Nuo Zhang, Chih-Ming Lin, Yi Rao, Univ. of California, Berkeley (United States); Debbie G. Senesky, Stanford Univ. (United States); Albert P. Pisano, Univ. of California, Berkeley (United States)

An integrated sensing module capable of operating at high temperatures up to 600 °C would be beneficial to a number of industrial applications, such as geothermal energy plant, aircraft engines, and industrial gas turbines. Silicon Carbide (SiC) is a promising semiconductor for harsh environment sensing applications due to its excellent electrical and physical properties. The most simple temperature sensor that can be integrated with a circuit is based on semiconductor diodes. SiC Schottky diodes have been proposed previously as temperature sensors that can work at temperatures up to 400 °C. However, SiC Schottky diodes suffer from high leakage current at elevated temperatures.

In this work, a 4H-SiC pn diode has been designed, fabricated and characterized. The device can stably operate in a temperature range from 20 °C up to 600 °C. In forward biased mode, the forward voltage of the 4H-SiC pn diode shows linear dependence on temperature at a constant current. This dependence is utilized to sense temperature variations and the proposed device achieves a sensitivity of 3.5 mV/°C, which is higher than the reported sensitivities of SiC Schottky diodes. These results indicate that an integrated circuit compatible temperature sensor based on 4H-SiC pn diode is a promising technology for harsh environment sensing applications.

9113-7, Session 2

Sensors for high temperature displacement, deformation and strain measurement: a review

Jiuhong Jia, East China Univ. of Science and Technology (China)

High temperature components are widely applied in aviation, power plant, petroleum and chemical industries. In these fields, high temperature displacement, deformation and strain measurement has been widely used to identify the presence, location, and severity of damage in components, owing to its sensitive characteristic to local defects. Displacement, deformation and strain have different definitions, but they can be easily calculated by corresponding equations. Therefore, recent publications regarding sensors applied in elevated temperature to measure displacement, deformation and strain are reviewed in this paper together. DDS is chosen to represent displacement, deformation and strain in the later review in order to simplify description. Firstly, the development histories of several typical high temperature DDS sensors are presented. Then, the performance parameters and respective characteristics of the latest research with different physical principles are listed, and some generalized methods on the selection of DDS sensors are concluded. Finally, the development levels of different kinds of sensors are generally analyzed by comparing published paper numbers in recent ten years. It can be concluded that the paper numbers about fiber optic sensors are much more than other types of sensors. Moreover, suggestions for future work are discussed in order to help students and early stage researchers.

9113-9, Session 3

High temperature sic pressure sensors with low offset voltage shift *(Invited Paper)*

Robert S. Okojie, NASA Glenn Research Ctr. (United States); Dorothy Lukco, Vantage Partners, LLC (United States) and NASA Glenn Research Ctr. (United States); Ender Savrun, Sienna Technologies, Inc. (United States)

We report the development of silicon carbide (SiC) piezoresistive pressure sensors with very low (~0.25 mV) shift in the zero pressure offset voltage (ZPO). Further, thermal cycling between room temperature and 500 ºC for 500 hours showed the transient ZPO drift to be minimal. This achievement reduces the error magnitude of the pressure sensor full-scale output voltage to ~ 0.43 % and ~ 1.4 % at 25 ºC and 500 ºC, respectively.

Pressure sensors are increasingly needed to monitor and measure pressure in high temperature (>500 ºC) environments. Applications of these sensors range from jet engine combustion chamber pressure monitoring for the purpose of real time recognition of the onset of thermo-acoustic instabilities to the future measurement of Venus atmospheric pressure where the temperature is 480 ºC. While recognized for its robustness over silicon at high temperature, SiC piezoresistive sensors do suffer from ZPO instability with increasing temperature. Since the ZPO is used as reference during pressure measurement, deviation from the calibrated value induces measurement error. Temperature compensation is impossible, since the transient drifts in the ZPO at high temperature are not repeatable.

Extensive analyses confirmed that the ZPO instability was driven largely by thermodynamics and zone reaction kinetics within the metal/semiconductor junction. This resulted in the optimization of the contact metallization to suppress such reactions enough to produce minimal shifts in the ZPO.

9113-10, Session 3

Mechanical properties of MEMS materials: reliability investigations by the combination of mechanical and HR-XRD characterizations with environmental testing *(Invited Paper)*

Tobias Bandi, Ctr. Suisse d'Electronique et de Microtechnique SA (Switzerland) and Ecole Polytechnique Fédérale de Lausanne (Switzerland); Herbert R. Shea, Ecole Polytechnique Fédérale de Lausanne (Switzerland); Antonia Neels, Ctr. Suisse d'Electronique et de Microtechnique SA (Switzerland)

The reliability of microelectromechanical systems (MEMS) inherently is of multifaceted nature due to the variety of influencing factors such as the operation modes, material properties, material interactions and the environmental conditions. Despite this challenging complexity, the performance and aging of devices is ultimately defined by the materials used. For microsystems with moving parts the mechanical properties are of special interest: For instance, resonant structures are at the heart of MEMS such as accelerometers, gyroscopes, pressure sensors, oscillators and resonant-mode filters. Their resonance characteristics are directly linked to the Young's modulus and Poisson's ratio of the moving element. Furthermore, structures under mechanical load or residual stresses are vulnerable to plastic deformation, fracture and creep.

This paper reviews and discusses recent advances and remaining challenges on methods to investigate mechanical properties of MEMS materials by the combination of mechanical characterization, high-resolution x-ray diffraction methods (HR-XRD), structural characterization and environmental testing. The measurement of resonance frequency variations of single-material microresonators allows monitoring minute variations of the elasticity in the ppm range induced by environmental hazards. Mechanical tests are used to investigate the failure distribution caused by mechanical loading. X-ray diffraction techniques enable analyzing residual strains, defects and deformations with high accuracy in crystalline materials. By using devices and test specimens with operation modes, fabrication processes and geometries which are relevant for functional MEMS devices, it is possible to account for characteristic size effects and fabrication-induced defect distributions.

Each of the test methods provides information on specific aspects of the mechanical properties of materials, and by combining them in-situ and ex-situ, a comprehensive understanding of the effect of hazardous conditions on MEMS materials can be achieved.

9113-11, Session 3

Development of an aluminum nitride-silicon carbide material set for high-temperature sensor applications *(Invited Paper)*

Benjamin A. Griffin, Scott Habermehl, Peggy J. Clews, Sandia National Labs. (United States)

A number of important energy and defense-related applications would benefit from sensors capable of withstanding extreme temperatures (>300°C). Examples include sensors for automobile engines, gas turbines, nuclear and coal power plants, and petroleum and geothermal well drilling. Military applications, such as hypersonic flight research, would also benefit from sensors capable of 1000°C. Silicon carbide (SiC) has long been recognized as a promising material for harsh environment sensors and electronics because it has the highest mechanical strength of semiconductors with the exception of diamond and its upper temperature limit exceeds 2500°C, where it sublimates rather than melts. Yet today, many advanced SiC MEMS are limited to lower temperatures because they are made from SiC films deposited on silicon wafers. Other limitations arise from sensor transduction by measuring changes in capacitance or resistance, which require biasing or modulation schemes that can withstand elevated temperatures. We are circumventing these issues by developing sensing structures directly on SiC wafers using SiC and piezoelectric aluminum nitride (AlN) thin films. SiC and AlN are a promising material combination due to their high thermal, electrical, and mechanical strength and closely matched coefficients of thermal expansion. AlN is also a non-ferroelectric piezoelectric material, enabling piezoelectric transduction at temperatures exceeding 1000°C. In this presentation, the challenges of incorporating these two materials into a compatible MEMS fabrication process are presented. The current progress and initial measurements of the fabrication process are shown. The future direction and the need for further investigation of the material set are addressed.

9113-12, Session 3

Characterization of gallium nitride surface acoustic wave resonators in radiation environments

Ashwin Shankar, Debbie G. Senesky, Stanford Univ. (United States)

Space environments contain harsh conditions such as extreme variation in temperature and radiation exposure. Conventional electronic components are prone to failure and drift when operated within space environments. As a result, electronic components are often shielded with heavy and complex packaging. New material platforms that leverage the radiation and temperature tolerance of wide bandgap materials can be used to develop robust electronic components without packaging. One such component that is vital for communication, navigation and signal processing on space exploration systems is the on-board timing reference, which is conventionally provided by a quartz crystal resonator and is prone to damage from radiation and temperature fluctuations. This paper presents the characterization of microfabricated, wide bandgap, gallium nitride (GaN) surface acoustic resonators (SAW) resonators in radiation environments. Ultimately, in combination with the two-dimensional gas (2DEG) layer at the AlGaN/GaN interface, high electron mobility transistor (HEMT) structures can provide a monolithic solution for timing electronics on board space systems. As a first step, 1-port and 2-port SAW resonators are microfabricated on a GaN-on-sapphire substrate to explore the impact of irradiation on the device performance. The SAW resonator was subjected to extreme temperature conditions to study the change in frequency response characteristics. Finite element modeling of the resonator has revealed a self-compensating property at cryogenic temperature. In addition, GaN-on-sapphire samples were irradiated with 150 krads of radiation using a Cs-137 source. The measured frequency response and X-Ray diffraction (XRD) spectrum of the GaN SAW resonators microfabricated from the irradiated samples are presented.

9113-13, Session 3

High temperature energy harvesters utilizing ALN/3C-SiC composite diaphragms

Yun-Ju Lai, Univ. of California, Berkeley (United States); Debbie G. Senesky, Stanford Univ. (United States); Albert P. Pisano, Univ. of California, San Diego (United States)

The growing interest in autonomous wireless sensor networks (WSNs) for condition-based structural health monitoring, where wireless sensors are distributed to target sites without considering to replace their power sources, spurs an obvious need of sustainable energy-harvesting based power sources to substitute conventional lifespan-limited batteries. Particularly, such power solutions become more essential for wireless sensors in harsh environments such as automotive engines, gas turbines, and geothermal/oil wells, where elevated temperatures (250°C-600°C) largely limit battery usage and maintenance for these sensor modules becomes much more difficult and cost-ineffective.

In this work, an aluminum nitride/cubic silicon carbide (AlN/3C–SiC) composite diaphragm enabling high-temperature energy harvesting from pulsed pressure sources for powering harsh-environment wireless sensors is presented. The micromachined energy harvester utilizing a unimorph circular diaphragm composed of thin film piezoelectric AlN and 3C–SiC, yields an output power density of 87 ?W/cm2 under 1.48-psi pressure pulses at 1 kHz. In addition, the fabricated device has been stably operated and characterized at temperature as high as 320°C, a thermal condition known to cause failure for lead-zirconate-titanate (PZT)-based devices due to dielectric de-poling.

The presented device represents the first energy-harvesting power source with experimentally verified stable operation at elevated temperatures >300°, showing great potentials for a sustainable power source that can be easily integrated with high temperature SiC-based circuitry and MEMS sensors, and therefore allow autonomous wireless sensing for a true long-lived, set-and-forget WSN for harsh environment applications. Work towards harvester demonstration at temperatures up to 600°C and analysis on temperature effects is underway.

9113-14, Session 3

Emerging GaN-based HEMTs for mechanical sensing within harsh environments

Helmut Köck, Stanford Univ. (United States) and Kompetenzzentrum Automobil- und Industrieelektronik GmbH (Austria); Caitlin A. Chapin, Stanford Univ. (United States); Clemens Ostermaier, Oliver Haeberlen, Infineon Technologies Austria AG (Austria); Debbie G. Senesky, Stanford Univ. (United States)

GaN-based HEMTs have been investigated thoroughly as a potential alternative to Si-based power transistors by academia and industry in the last decade. It is well known that GaN-based HEMTs outperform Si-based technologies in terms of power densities, area specific on-state resistance and switching speed. Recently, wide band gap material systems have stirred a profound interest regarding their use in various sensing fields ranging from chemical, mechanical, biological to optical applications due to their superior material properties. For harsh environments, wide band gap sensor systems are deemed to be superior compared to conventional Si-based systems. A new sensor generation will enable engineers the design of highly efficient propulsion concepts versatility applicable to automotive, aeronautics and astronautics systems.

In this paper, the advances of GaN-based HEMTs for mechanical sensing applications are discussed. Of particular interest are multilayered heterogeneous structures where spontaneous and piezoelectric polarization between the interface results in the formation of a 2-dimensional electron gas (2DEG), achieving large carrier densities in the order of 1e13 cm-2. Experimental results presented focus on the signal transduction under strained operating conditions in harsh environments. It is shown that a conventional AlGaN/GaN HEMT shows a strong dependence of drain current under strained conditions, thus representing a promising future sensor platform. Ultimately, this work explores the sensor performance of conventional GaN HEMTs and leverages existing technological advances available in power electronics device research. The results presented have the potential to boost GaN-based sensor development through the integration of HEMT device and sensor design research.

9113-15, Session 4

Monitoring corrosion in reinforced concrete structures *(Invited Paper)*

Peter Kung, QPS Photronics Inc. (Canada); Maria Cominici, McGill

Univ. (Canada)

Many defects can cause deterioration and cracks in concrete; these are results of poor concrete mix, poor workmanship, inadequate design, shrinkage, chemical and environmental attack, physical or mechanical damage, and corrosion of Reinforcing Steel (RS). We want to develop a suite of sensors and system that can detect that corrosion is taking place in RS and inform owners how serious the problem is. By understanding the stages of the corrosion process, we can develop special sensor that detects each transition. First, moisture ingress can be monitored by a fiber optics humidity sensor, then ingress of Chloride, which acts as a catalyst and accelerates the corrosion process, converting iron into ferrous compounds. We need a fiber optics sensor which can quantify Chloride ingress over time. Converting ferric to ferrous causes large volume expansion and cracks. Such pressure build-up can be detected by a Fibre-optics pressure sensor.

Finally, cracks will introduce acoustic emission, which can be detected by a high frequency sensor made with phase-shift gratings. This paper will discuss the progress in our development of these special sensors and also our plan for a field test by the end of 2014. We recommend that we deploy these sensors by visually inspecting the affected area and by identifying locations of corrosion; then, work with the designers to identify spots that would compromise the integrity of the structure; finally, drill a small hole in the concrete and insert these sensors. Interrogation can be done at fixed intervals with a portable unit.

9113-17, Session 4

Rainfall compensation scheme in distributed optical-fiber vibration sensor engineering system

Hui Zhu, Chao Pan, Xiaohan Sun, Southeast Univ. (China)

Recently, distributed optical-fiber vibration sensing technique has been widely used to locate broken points and detect intrusion in the field such as underground pipeline monitoring and perimeter security, and more and more practical systems are implemented. However, it is difficult to distinguish between normal disturbance and environmental impact when sensing fiber is exposed to the harsh climatic environment, because noises caused by harsh climatic drown the sensing signals. Rainfall is obviously an important factor which can produce the large noise in the rainy season. In this paper, we demonstrated a scheme for compensating the signal with large noise induced by rainfall in the distributed optical-fiber vibration sensor engineering system (DFVSES).

The DFVSES with rainfall compensation is made up of two subsystems using a common optical source and same optical circuit, one of which is the sensing subsystem and another is the reference one, both can produce the noise signals caused by rainfall. The fiber cable in sensing subsystem is lay on the perimeter as the sensing element, and the fiber cable in reference subsystem is shorter and fixed on a funnel which should be only disturbed by rainfall. By analyzing spectrum of the noise signals produced by rainfall in the reference subsystem, and comparing the output signals of the two subsystems, the vibration signals can be extracted through denoising the output signals of the sensing subsystems. We set up the experimental system, and the results show the scheme can reduce effectively the impact of the rainfall on the sensing signal.

9113-18, Session 4

A miniaturized optical package for shear stress measurements in harsh environments

Tai-An Chen, David A. Mills, Vijay Chandrasekharan, Mark Sheplak, Univ. of Florida (United States)

We report the development of a time-resolved direct shear stress sensing technique using an optical moiré transduction technique for harsh environments. The floating-element-based sensor is a lateral-position sensor that is micromachined to enable sufficient bandwidth and to avoid spatial aliasing [1,2]. The optical transduction approach offers several advantages over electrical-based floating element techniques [3–6] including immunity from EMI and the ability to operate in a conductive fluid medium.

Packaging for optical sensors presents significant challenges. The bulky nature and size of conventional free-space optics often limit their use to an optical test bench, making them unsuitable for harsh environments [7]. The optical package developed in this research utilizes an array of optical fibers mapped over the moiré fringe. The fiber bundle approach results in a robust package that reduces the overall size of the optics, mitigates vibration between the sensor and optoelectronics and enables in situ measurement.

The optical package using the moiré amplification is evaluated using test setups and through modeling. An optical test bench is constructed to simulate the movement of the moiré fringe on the floating element. High-resolution images of the optical fringe and optical fibers are combined in simulation to model the lateral displacement of the fringe. The performance of several fringe estimation algorithms are studied and evaluated.

Based on the optical study, the optical package and post-processing algorithms are implemented on an actual device. Initial device characterization using this approach results in a device sensitivity of 12.4 nm/Pa.

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9113-19, Session 4

Development of a sapphire optical pressure sensor for high-temperature applications

David A. Mills, Dylan Alexander, Ghatu Subhash, Mark Sheplak, Univ. of Florida (United States)

This research presents the fabrication and packaging of a sapphire optical pressure sensor for high-temperature applications. Currently available instrumentation poses significant limitations on the ability to achieve real-time, continuous measurements in high-temperature environments such as those encountered in industrial gas turbines and high-speed aircraft. For these applications, fiber-optic sensors provide several advantages over traditional electrical sensing methods including being passive, immune to electromagnetic interference, and nonconductive. Sapphire further enhances these qualities due to its high chemical inertness and operating temperature range; however, a lack of well-established micromachining processes necessitates the development of innovative processes to enable the fabrication of three-dimensional mechanical structures.

The fiber-optic lever transduction mechanism employed utilizes the deflection of a circular platinum-coated sapphire diaphragm to modulate the light reflected back to a single send/receive sapphire optical fiber. A

10 ps, 355 nm wavelength ultra-short pulse laser is used to pattern the sapphire back cavity for the sensor with minimal thermal damage using a pulse overlap of 86% and laser fluence of 4.48 J/cm2. The 7 mm diameter, 50 μm thick diaphragm is attached using a novel thermocompression bonding process based on spark plasma sintering technology. Bonds using platinum as an intermediate layer are achieved at a temperature of 1200°C with a hold time of 5 min. Initial characterization of the bond interface using a simple tensile test resulted in a strength in excess of 12 MPa. The packaged sensor enables continuous operation up to 900°C with a resonance of 22.1 kHz and theoretical sensitivity of 0.12 ?V/V/Pa.

9113-20, Session 5

Robust MEMS gyroscope for oil and gas exploration *(Invited Paper)*

David Lin, Todd Miller, GE Global Research (United States)

To satisfy the performance and reliability requirement of a MEMS based harsh environment sensor, the sensor development needs to depart from the classic method of single-discipline technology improvement. In this paper, the authors will describe a Microsystem-based design methodology which considers simultaneously multiple technology domains and achieves performance optimization at the system level to address the harsh environment sensing challenge. This is demonstrated through specific examples of investigating a robust MEMS gyroscope suitable for high temperature and high vibration environments such as down-hole drilling for Oil and Gas applications. In particular, the different mechanisms of temperature-induced errors in MEMS gyroscope are discussed. The error sources include both the direct impact of the gyroscope dynamics by temperature and the indirect perturbation by temperature-induced package stress. For vibration and shock induced failure, the error contributions from the low frequency and high frequency contents are discussed. Different transducer designs with equivalent rate sensitivity can vary with several orders of magnitude in terms of the susceptibility to mechanical vibration. Also shown are the complex interactions among the gyroscopic transducer, packaging and the control electronics, resulted from these temperature and vibration error sources. The microsystem-based design methodology is able to capture such complex interactions and help improve the gyroscope temperature and vibration performance.

In contrast to other efforts in harsh environment sensing which focus on specific domains of technologies, the authors strive to demonstrate the need and advantage of addressing MEMS performance and reliability in harsh environment from a Microsystem perspective.

9113-21, Session 5

Development of a downhole tool for measuring real-time concentration of ionic tracers and pH in geothermal reservoirs

Grzegorz G. Cieslewski, Ryan F. Hess, Scott Lindblom, Timothy J. Boyle, Sandia National Labs. (United States); Greg Stillman, U.S. Dept. of Energy (United States); William G. Yelton, Steven J. Limmer, Sandia National Labs. (United States)

Proper monitoring of geothermal reservoirs is essential for developing and maintaining productivity of the geothermal field. Enhanced or Engineered Geothermal Systems (EGS) extract heat by circulating fluid through fracture network in subsurface rock formations. The hot geothermal brine is pumped to the surface via the production wells, heat extracted, and spent brine is re-injected via the injection wells. Chemical tracers are commonly used to characterize the fracture network and determine the connectivity between the injection and production wells. Currently, most tracer experiments involve injecting the tracer at the injection well, manually collecting liquid samples at the wellhead of the production well, and sending the samples off for laboratory analysis. While this method provides accurate tracer concentration data at very low levels of detection it does not provide information regarding the location of the fractures which were conducting the tracer between wellbores. Sandia is developing a high-temperature electrochemical sensor capable of measuring tracer concentrations and pH downhole on a wireline tool. The goal of this effort is to collect real-time pH and ionic tracer concentration data at temperatures up to 225 °C and pressures up to 5000 psi. In this paper, we will present a prototype electrochemical sensor and data showing the measurement of Li+, Cs+, F-, and I- concentrations at high temperature and pressure in a laboratory scale autoclave.

9113-22, Session 5

Modeling and fabrication of a low cost passive wireless temperature sensor using metamaterials

Hasanul Karim, Diego Delfin, Mohammad Arif I. Shuvo, Raymond C. Rumpf, Ryan B. Wicker, Ahsan Choudhuri, Yirong Lin, The Univ. of Texas at El Paso (United States)

Wireless passive temperature sensors are receiving increasing attention due to the ever-growing need of energy efficient and precise monitoring of temperature in high temperature energy conversion systems such as gas turbines and coal-based power plants. Unfortunately, the harsh environment such as high temperature and corrosive atmosphere present in these systems has significantly limited the reliability and increased the cost of current solutions. Therefore, this paper presents the design, simulation and manufacturing process of a low cost, passive, and wireless temperature sensor that can withstand high temperature and harsh environment. The temperature sensor was designed following the principle of metamaterials by utilizing Closed Ring Resonators (CRR) in a dielectric matrix. The proposed wireless, passive temperature sensor behaves like an LC circuit, which has a resonance frequency that is temperature dependent. A full wave electromagnetic solver Ansys Ansoft HFSS was used to perform simulations to determine the optimum dimension and geometry of the sensor unit. Both ceramic-binder based 3D printing and metal-die compression were used to fabricate the sensor. Testing will be performed and compared with the simulation results to demonstrate the temperature sensing capabilities of the fabricated sensor.

9113-23, Session 5

Open architecture health monitoring and analysis for large structures and a distributed network of synchronized strain sensors

James Morrison, Robert Klug, Jonathan Williams, McQ, Inc. (United States)

McQ Inc. is a leading provider of high performance, advanced technology unattended ground sensor (UGS) systems. Our research spans two decades of investigating technologies suitable for automatically detecting, imaging, and tracking targets. This also includes novel data processing and communications expertise gained through the development of classification algorithms and network protocols specifically designed for low power operation, accurate sensing of targets, and reliable notification. Through two independent programs, we have developed a structural health monitoring (SHM) sensor system and a software toolset for analyzing data collected from a variety of SHM sensor systems. Our investigations and engineering have lead to two operational prototype systems that are capable of collecting synchronized structural health data and providing valuable information for planning the operation and maintenance of Naval ships.

A strain monitoring system that is simple, unobtrusive, and highly reliable is invaluable for assessing the health of Navy vessels. The strain acquisition and monitoring system (SAMS) consists of a scalable network of distributed miniature data acquisition modules that acquire, condition, and digitize strain signals. The Integrated Naval Ship Condition Assessment Toolset (INSCAT) is comprised of several software subsystems integrated into a single toolset for monitoring the structural health of naval ships. The INSCAT includes a multi-tiered UI to display pertinent SHM data, AI (SOM) based SHM algorithms for real time situational awareness and long term SHM oversight, and a flexible data interface to facilitate integration with current Navy systems.

9113-24, Session 6

Magnetoresistive sensors for angle, position, and electrical current measurement in demanding environments

Rolf Slatter, Ronald Lehndorff, Johannes Paul, Marco Doms, Sensitec GmbH (Germany)

The magnetoresistive effect is best known from the read heads of computer hard discs or from magnetic memory (MRAM) applications, but it is also well suited to uses in sensor technology. It has a long history, the anisotropic magnetoresistive (AMR) effect being first discovered in 1857 by Lord Kelvin. The AMR effect occurs in ferromagnetic materials, such as nickel-iron layers structured as strip elements, whose specific impedance changes with the direction of an applied magnetic field. Due to a special structure of the strips the resistance change is proportional to the applied magnetic field over a wide range.

However, the MR-effect did not experience widespread use until the early 1980s, when the first MR-based read heads were implemented in hard disc drives. The first industrial applications for MR-based sensors followed at the beginning of the 1990s, since when the number of applications has increased dramatically. The applications are not only limited to terrestrial use – MR sensors are used to control the electric drives used on “Curiosity”, the Planetary Rover that landed successfully on Mars in August 2012. MR sensors are also used extensively in safety-critical automotive applications, for example in wheel speed sensors for the ABS (anti-lock braking) system or in steering angle sensors for the ESP (electronic stability program) system.

The paper will describe the principle of operation, manufacturing process and benefits of MR sensors. This will be followed by a description of practical application examples from the automotive, oil & gas, renewable energy and space fields, where MR sensors are successfully applied in very small envelopes at very low /very high temperatures, under high pressure, high mechanical loading and under strong radiation.

9113-25, Session 6

High-sensitivity trace gas sensor at 30-km altitude

Douglas Maukonen, Andrey V. Muraviev, Christopher J. Fredricksen, Joshua Colwell, Ammar Alhasan, Robert E. Peale, Univ. of Central Florida (United States)

The Planetary Atmospheres Minor Species Sensor (PAMSS) is a mid-infrared intracavity laser absorption spectrometer based on an external cavity quantum cascade laser. The prototype system has achieved technical readiness level (TRL) 4 with laboratory demonstrated near-real-time sensitivity to molecular absorption coefficients as small as 1 x 10^-5 cm^-1. This is equivalent to a mixing ratio as small as 30 ppbv at 1 atm. The present objective is to raise the TRL to 6 by testing PAMSS in near space. The extreme low pressures that eliminate convective cooling and temperatures below -60 C present several optical alignment, electronics, and thermal management challenges. We present the results of PAMSS's flight to 30 km in Near Space Corporation's Small Balloon System. Technologies tested during the flight involve heat transfer and re-use, and autonomous data collection using commercial off-the-shelf components, and self-alignment techniques to ensure data gathering throughout the flight. The science value for solar-system exploration is that trace gasses are indicative of biologic activities and geologic activities on planets, asteroids, and comets, and detection of trace gasses on Earth can also advance our understanding human impact on climate change. The test results are relevant to defense-related chemical sensing in extreme environments.

9113-26, Session 6

Harsh electronics: materials and electronic device development

Dung-Sheng Tsai, Jr-Hau He, National Taiwan Univ. (Taiwan)

Electronic products today are often used in extreme harsh environments such as high temperature, aggressive media, extreme vibration and radiation exposure. It is very important that as considering the constrains for above-mentioned practical applications, the operation of electronic system in extreme environments is required inevitably. To ensure high reliability, it is necessary to develop new generation electronics for extreme harsh environment applications.

An overview of research works on harsh electronics at He's group will be presented. Work highlighted will include design, fabrication, and application of photodetectors, thin-film transistors, solar cells and memory devices in harsh environments.

9113-27, Session 6

Remote optical detection of alpha particle sources from joint Russian-Ukrainian R&D team

Andrey Bashchenko, GeoSpex Sciences (Russian Federation); Sergiy Baschenko, Institute of Physics (Ukraine)

Spectral investigations of the alpha-radioluminescence phenomenon in the atmosphere have been carried out in the UV–V region. It was found that: (1) more than 95% of the intensity of the alpha radiation induced luminescence (alpha-radioluminescence) falls in the narrow range between 310 and 400 nm, (2) the alpha-radioluminescence spectrum consists of a small number of bands typically 2–3 nm wide and belonging to the 2+ system of nitrogen molecule transitions, (3) each alpha particle emitted from the surface causes creation of approximately 30 UV photons in ambient air, (4) alpha particles emitted from the source surface have an angular distribution proportional approximately to cos8(?).

By determining the main features of the alpha-radioluminescence spectrum, it should be possible to design optical methods and techniques for the indirect remote detection of alpha particle sources even in the presence of a high background of beta or gamma radiation. With the aim of proving this possibility, a laboratory model of an optical receiving system was designed and tested. From a distance of 30 m, the optical image of a clean alpha source (239Pu, 3.7 ? 107 Bq) placed close to a high activity gamma ray source (60Co, 18.5 ? 107 Bq) was captured photographically by the model system.

The possibility of the practical indoor implementation of such a passive optical method for the remote (hundreds of metres) detection of alpha particle sources even in intense beta/gamma radiation fields is discussed. The potential for an active version of the method is also considered.

9113-29, Session 6

Qualification of quantum cascade lasers for space environments

Tanya L. Myers, Bret D. Cannon, Carolyn S. Brauer, Pacific Northwest National Lab. (United States); Blake G. Crowther, Utah State Univ. Research Foundation (United States) and Space Dynamics Lab. (United States); Stewart Hansen, Utah State Univ. (United States)

Laser-based instruments are enabling a new generation of scientific instruments for space environments such as those used in the exploration of Mars. The lasers must be robust and able to withstand the harsh environment of space, including radiation exposure. Quantum cascade lasers (QCLs), which are semiconductor lasers that emit in the infrared spectral region, offer the potential for the development of novel laser-based instruments for space applications. The performance of QCLs after radiation exposure, however, has not been published. Thus, in this paper, we report on work to quantify the performance of QCLs after exposure to different radiation sources including protons and gamma rays to determine the effects of radiation damage.

9113-4, Session Posters-Thursday

Thin film transistors based on hafnium indium zinc oxide (HIZO) with high radiation tolerance

Dung-Sheng Tsai, Shih-Guo Yang, Meng-Lin Tsai, Der-Hsien Lien, National Taiwan Univ. (Taiwan); Kuan-Ming Chen, Yueh-Chung Yu, Academia Sinica (Taiwan); Jr-Hau He, National Taiwan Univ. (Taiwan)

This work demonstrates the high radiation tolerance of TFTs up to ?1015 cm-2 using HIZO films from co-sputtering of IZO and Hf targets at RT. Under 2-MeV proton irradiation, the VGS–IDS characteristics of HIZO TFTs degrade with the fluences ranging from 0 cm-2 (pristine) to 1013 cm-2 and then recover to a initial level of the pristine with increasing the proton radiation fluences up to ~1015 cm-2. That indicates that the interface could be improved via dynamic annealing effects under high proton irradiation fluences. The C-V curves of HIZO TFTs are also measured and consistent with the VGS–IDS characteristics of HIZO TFTs. These results support the use of HIZO TFTs in high radiation environments.

9113-41, Session Posters-Thursday

A two laser noise estimation technique to reduce the effects of 1/f noise in open path tunable diode laser absorption spectrometry (OP-TDLAS)

Israa L. Mohammad, Univ. of Arkansas at Little Rock (United States) and The Univ. of Mustansiriyah (Iraq); Gary Anderson, Youhua Chen, Univ. of Arkansas at Little Rock (United States)

Many techniques using high frequency modulation have been proposed to reduce the effects of 1/f noise in tunable diode-laser absorption spectroscopy (TDLAS). The instruments and devices used by these techniques are not suitable for space applications that require small, low mass and low power instrumentation. A new noise estimation technique using two-laser beams excited at slightly different frequencies have been proposed to reduce the effect of 1/f noise at lower frequencies. The two lasers are excited at slightly different frequencies, giving two different harmonics that can be used to estimate the total noise in the measurement. Indoor experimental results on ammonia gas validate the 1/f noise is effectively reduced by the new noise estimation technique. Experimental results indicate that the effect of 1/f noise is reduced to 1/5 its normal value.

Conference 9114: Advanced Photon Counting Techniques VIII

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9114-1, Session 1

Device physics to receiving photons from lunar orbit: an evolution of superconducting nanowire single photon detectors *(Keynote Presentation)*

Eric A. Dauler, Andrew J. Kerman, Matthew E. Grein, Danna Rosenberg, Matthew M. Willis, Jan E. Kansky, Bryan S. Robinson, Daniel V. Murphy, Don M. Boroson, MIT Lincoln Lab. (United States)

Technology development is driven by understanding both the details of the device operation and the performance desired by target applications. The recent evolution of superconducting nanowire single photon detector technology, particularly in support of the first high-rate, optical communication link from a satellite in lunar orbit, provides insight into this technology development process and some opportunities for future advances. The evolution of the detector design was driven not only by the application needs, but as the result of innovations that were closely connected to our understanding of the detector operation.

Over the past decade, major advances have been made in understanding many aspects of superconducting nanowire single photon detector operation. In particular, the optical absorption and the electro-thermal behavior of the nanowires can be quantitatively modeled, allowing devices to be designed that account accurately for these effects. Furthermore, the impact of using different substrate and superconducting materials and the effect of different nanowire geometries (including closely-spaced, electrically-independent wires) have also been studied.

More recently, system requirements have motivated specific advancements in the detector performance. The development path taken to achieve these performance improvements involved design innovations in the electrical readout, the optical coupling and the detector structure itself. The strong connection between the models of detector operation and the innovations that were developed and adopted will be highlighted. Furthermore, parallels to other single-photon detector array development efforts and implications for future technology development will also be discussed.

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9114-2, Session 1

Tungsten silicide superconducting nanowire single photon detector arrays for deep space optical communication *(Invited Paper)*

Matthew D. Shaw, Francesco Marsili, Andrew D. Beyer, William H. Farr, Jet Propulsion Lab. (United States); Giovanni Resta, Politecnico di Torino (Italy); Varun B. Verma, Robert D. Horansky, Adriana Lita, Richard P. Mirin, Sae Woo Nam, National Institute of Standards and Technology (United States)

We report on the development of tungsten silicide superconducting nanowire single photon detector (SNSPD) arrays at the Jet Propulsion Laboratory. We discuss the development of large-format SNSPD focal planes, free space optical coupling performance, strategies for dark count mitigation and blackbody rejection, and advanced readout technology. In particular, we discuss the use of monolithic SiGe readout integrated circuits to combine detector channels for optical communication applications. We also discuss spatial multiplexing experiments using SNSPD arrays, and the prospects for using SNSPD arrays for deep space optical communication under realistic conditions. We will discuss strategies for scaling this SNSPD architecture toward kilopixel arrays, in terms of focal plane design, device architecture, and readout electronics.

9114-3, Session 1

Cryogenic SiGe integrated circuits for superconducting nanowire single photon detector readout *(Invited Paper)*

Joseph C. Bardin, Prasana Ravindran, Su-Wei Chang, Univ. of Massachusetts Amherst (United States); Charif Mohamed, The Univ. of New Hampshire (United States); Matthew D. Shaw, Francesco Marsili, Giovanni Resta, William H. Farr, Jet Propulsion Lab. (United States)

As the performance of superconducting nanowire single photon detectors (SNSPDs) has improved drastically over the past several years, there is a growing interest in developing sophisticated systems employing large arrays of SNSPDs. In order to make such systems practical and to extract the maximum level of performance from these devices, it is desirable to develop the technology to perform signal processing functions before transporting signals to room temperature. In this paper, we will review recent progress in the design, implementation, and testing of Silicon Germanium (SiGe) integrated circuits for the readout of SNSPDs. In particular, we will present the design and characterization of a cryogenic eight-channel pixel combiner circuit designed to read-out arrays of SNSPDs. The circuit is designed to amplify, digitize, edge detect, and combine the output signals of an array of eight SNSPDs. The design has been enabled by the development of novel large-signal cryogenic SiGe HBT simulation models. The circuit has been fabricated and measurement results demonstrate excellent agreement with simulation. The paper will conclude with a summary of ongoing work and future directions.

9114-4, Session 2

Photon-number-resolving detectors for photonic on-chip quantum information *(Invited Paper)*

Thomas Gerrits, National Institute of Standards and Technology (United States)

We demonstrate a high-efficiency, photon-number resolving transition edge sensor, integrated on an optical silica waveguide structure. The new design employs a detector/absorber design to enhance the photon absorption inside the optical waveguide, enabling high fidelity detection of quantum information processes in on-chip platforms. We found that photon number resolution of the TES is well observed with the added absorber material. The derived detection efficiency for the TM input polarization is 79.0 ± 2.0%. This is the efficiency with which a photon inside the waveguide will be detected. This does not account for the coupling efficiency from the optical fiber to the waveguide. In this case the coupling efficiencies are 22.1 ± 0.3% and 14.8 ± 0.2% for the either side of the waveguide chip. When tuning our laser to an integrated high-reflector wavelength of 1551.9 nm, we observe a quantum efficiency of 88%, as the photons now pass each absorber/sensor twice. The results are in very good agreement with the results from our optical modeling and show the ability to accurately tune the detection efficiency of a detector. The ability to tailor the detection efficiency of each detector enables a partially reflecting beamsplitter and a very well mode-matched number resolving single photon detector using just one single element placed on top of the waveguide structure. We will show how such a design allows for a range of photon-subtraction/addition experiments to be carried out on-chip for the first time.

9114-5, Session 2

Photon-number-resolving detectors for GaAs waveguide quantum circuits *(Invited Paper)*

Dondu Sahin, Technische Univ. Eindhoven (Netherlands); Alessandro Gaggero, Istituto di Fotonica e Nanotecnologie (Italy); Zili Zhou, Saeedeh Jahanmirinejad, Technische Univ. Eindhoven (Netherlands); Francesco Mattioli, Roberto Leoni, Istituto di Fotonica e Nanotecnologie (Italy); Johannes Beetz, Matthias Lermer, Martin Kamp, Sven Höfling, Julius-Maximilians-Univ. Würzburg (Germany); Andrea Fiore, Technische Univ. Eindhoven (Netherlands)

Single-photon sources, passive optical elements and single-photon detectors constitute the basis of the monolithic integration of quantum photonic circuits, as needed for scaling photonic quantum information protocols to tens of qubits. However, integrated quantum photonics has so far been limited to passive implementations, due to the difficulty of integrating the detectors on the same substrate with the sources and the waveguides.

To this aim, we have recently demonstrated the first waveguide single-photon detectors (WSPDs) [1] and polarisation-independent, integrated autocorrelators for the on-chip measurements of the second-order correlation function, g(2)(τ) [2]. The detectors are based on superconducting NbN nanowires, located on top of GaAs ridge waveguides. In this work, we report the integration of photon-number-resolving detectors (PNRDs) on top of GaAs ridge waveguides. These detectors are based on an array of four superconducting nanowires, each exploiting the same geometry of WSPDs [1], and therefore able to measure up to four photons. Each wire is connected in parallel to an integrated resistance and in series to the other wires. When a coherent light beam is coupled into the waveguide, four clearly-resolved output levels are observed [3]. The PNRDs show device quantum efficiencies of 24% and 22% at 1310 nm for the TE and TM polarisations with an estimated maximum count rate of >50 MHz. These detectors are highly suited for high-speed quantum information processing and linear-optics quantum computing.

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9114-6, Session 2

Characterization of superconducting nanowire single-photon detector with artificial constrictions

Ling Zhang, Lixing You, Dengkuan Liu, Weijun Zhang, Xiaoyu Liu, Junjie Wu, Yuhao He, Chaolin Lv, Zhen Wang, Shanghai Institute of Microsystem and Information Technology (China)

Statistical studies on the performance of different superconducting nanowire single-photon detectors (SNSPDs) on one chip suggested that random constrictions existed in the nanowire. However, they were barely registered by scanning electron microscopy or other tools. With the aid of advanced e-beam lithography, artificial geometric constrictions with specific sizes were fabricated on SNSPDs as well as single nanowires. In this way, we studied the influence of artificial constrictions on SNSPDs in a straight forward manner. By introducing artificial constrictions with different widths in single nanowires, we found a consistent linear relationship between the dark count rate and the bias current, which indicated that the dark counts of SNSPDs originate from a single constriction. By introducing artificial constrictions in SNSPDs, we studied the relationship between detection efficiency and the bias current. The result of DE-Ib relation was similar to the previous statistical studies. Further, it is consistent with the width of the constriction. Meanwhile, we examined the current dependence of the kinetic inductance Lk for the above SNSPDs. The results were also similar to the statistical studies, thus confirming the hypothesis that constrictions exist in SNSPDs.

9114-7, Session 3

Progress towards implementation of a quantum communication receiver satellite *(Invited Paper)*

Thomas D. Jennewein, Brendon L. Higgins, Jean-Philippe Bourgoin, Catherine Holloway, Christopher Pugh, Nick Gigov, Raymond Laflamme, Univ. of Waterloo (Canada)

Quantum information and quantum entanglement enables new protocols for communication tasks not possible with classical system. One very important example is the secure key exchange based on the transmission of individual quantum bits. A global quantum internet, comprised of a network quantum communication and quantum entanglement is a long term vision, and there is a significant amount of research on how to reach this goal. Satellite based quantum communication based on optical photons is a very promising system, as it offers the potential to perform global coverage with today's technology.

I will present the mission proposal for QEYSSAt, the proposed quantum encryption and science satellite pursued in Canada, aiming to place a single-photon quantum receiver in space. This system is planned to incorporate a photon analyzer and photon detector, capable of demonstrating global quantum key exchange as well as tests of quantum entanglement and quantum teleportation. in particular, I will outline the performance analysis of the quantum key exchange, and present our recent advances towards implementing and testing the required subsystems of the payload.

9114-8, Session 3

A compact high-performance gigahertz-gated SPAD in an actively stabilized RF-interferometer

Alessandro Restelli, Joint Quantum Institute (United States); Joshua C. Bienfang, Alan L. Migdall, National Institute of Standards and Technology (United States)

It has been shown that for gigahertz-gated InGaAs/InP single-photon avalanche diodes (SPADs) in which the gate is composed of sinusoids, the capacitive transient can be effectively suppressed by destructive interference with reference sinusoids. Using this approach, we have built a compact detection system gated at 1.25 GHz that applies bias gates exceeding 35 Vpp at the cathode, and achieves suppression of the capacitive transient at the anode sufficient to use avalanche discrimination thresholds in the millivolt range. The gate signal is composed of four harmonics of the gate frequency (up to 5 GHz), and achieves gate durations below 150 ps. The reference signal must maintain a match to the capacitive transient to better than 10^-4 to ensure operation limited by the noise floor of the broadband low-noise amplifier at the system's output.

To maintain this the system actively controls the phase and amplitude of each of the four harmonics in the reference signal, achieving stable and high-quality transient rejection. We describe the microcontroller-based circuit, and the performance of the detection system when operated at count rates in the 100 x 10^6 s^-1 range.

9114-9, Session 3

Detector-related security loopholes in quantum cryptography *(Invited Paper)*

Vadim Makarov, Univ. of Waterloo (Canada)

Single-photon detector is a tricky device to build, with many imperfections. When used in quantum cryptography systems, its imperfections open up ways to compromise system security. The talk reviews attacks based on detector imperfections, and recent progress in development of countermeasures.

9114-10, Session 4

Photon sparse imaging *(Invited Paper)*

Miles J. Padgett, Univ. of Glasgow (United Kingdom)

How many photons does it take to form an image? Although a single photon can be spatially encoded to carry large amounts of information, real images are not fully orthogonal to each other and hence, realistically, require many detected photons to distinguish between them. Even if one has access to a pixellated imaging detector with high quantum-efficiency, the fidelity of a recorded, or inferred, image depends critically upon the dark counts from the detector(s). Here we will present our latest results using heralded single-photons and a time-gated, intensified-camera to all but eliminate noise events, and record images of biological specimens. The images are formed from low photon-number and are therefore subject to a noise inherent within the Poissonian distribution of single-photon events. We apply techniques of compressive sensing and image regularisation to obtain good estimates of the object, obtained for ultra-low optical exposures.

9114-11, Session 4

Low-noise CMOS SPAD arrays with in-pixel time-to-digital converters *(Invited Paper)*

Alberto Tosi, Federica A. Villa, Danilo Bronzi, Yu Zou, Davide Tamborini, Politecnico di Milano (Italy); Simone Tisa, Micro Photon Devices S.r.l. (Italy); Daniel Durini, Sascha Weyers, Uwe Paschen, Werner Brockherde, Fraunhofer-Institut für Mikroelektronische Schaltungen und Systeme (Germany); Franco Zappa, Politecnico di Milano (Italy)

We present our latest results concerning CMOS Single-Photon Avalanche Diode (SPAD) arrays for high-throughput parallel single-photon counting. We exploited a high-voltage 0.35 µm CMOS technology in order to develop low-noise CMOS SPADs. The Dark Count Rate is 30 cps at room temperature for 30 µm devices, increases to 2 kcps for 100 µm SPADs and just to 100 kcps for 500 µm ones. Afterpulsing is less than 2% for hold-off time longer than 50 ns, thus allowing to reach high count rates. Photon Detection Efficiency is > 50% at 420 nm, > 40% below 500 nm and is still 5% at 850 nm. Timing jitter is less than 100 ps (FWHM) in SPADs with active area diameter up to 50 µm.

We developed CMOS SPAD imagers with 150 µm pixel pitch and 30 µm SPADs. A 64x32 SPAD array is based on pixels with three 9 bit up/down counters for smart time-resolved photon counting up to 100 kfps. A 32x32 SPAD array includes 1024 10 bit Time-to-Digital Converters (TDC) with 300 ps resolution and 450 ps single-shot precision, for 3D ranging and FLIM. We developed also linear arrays with up to 60 pixels (with 100 µm SPAD, 150 µm pitch and in-pixel 300 ps TDC) for time-resolved parallel spectroscopy with high fill factor.

9114-12, Session 4

Evaluation of GM-APD array devices for low-light-level imaging

Kimberly E. Kolb, Brandon J. Hanold, Joong Y. Lee, Donald F. Figer, Rochester Institute of Technology (United States)

The ability to count single photons facilitates science goals that are impossible even with current state-of-the-art detectors. Single photon counting detectors are the future, and many different implementations are in development. This paper will evaluate the performance of a photon-counting array-based Geiger-mode avalanche photodiode for low-light-level imaging. Laboratory testing results are presented as a basis for evaluation. These results include dark count rate, afterpulsing probability, photon detection efficiency, and intra-pixel sensitivity. The detector was irradiated with a radiation dose equivalent to 10x the expected dose for an 11 year mission at an L2 orbit. All detector performance metrics are presented both pre- and post-radiation. The theoretical signal to noise ratio is presented as the overall evaluation method, based on measured results. The GM-APD detector performance will be compared to current state-of-the-art CCD and EMCCD performance in a low-light-level scenario. Theoretical process improvements and their impact on the GM-APD detector performance are also considered.

9114-13, Session 4

Near-infrared silicon photon-counting arrays

Stefan A. Vasile, aPeak, Inc. (United States)

Under a contract from JPL/NASA we developed a photon counting array for long-range communications at 1030nm with beam tracking and communication functions. The response at 1030nm is enhanced using the resonant cavity effect.

NIR enhanced photon-counting Resonant Cavity Geiger avalanche Photodiode (RC-GPD) arrays assembled with matching 32x32 pixel ROIC arrays were qualified in 2013. ROIC arrays with 130um x130um pixel size with active quenching, afterpulsing control (APC), write-read functions at pixel level and integrated twin-read drivers were fabricated in 2012. The twin-drivers allow reading either the whole 32x32 pixel array or simultaneous reading of two 16x32 sub-arrays at maximum 160MHz clock rate. Because the count memory cell at pixel level copies constantly the data to the output shift register the ROIC array should be able of continue counting while shifting the data out. The ROIC is capable of counting in UP and DOWN modes to allow for automatic electronic+optical background subtraction in tracking mode.

Process improvements of the RC-GPD back-end fabrication resulted in a robust cavity tuning process with 50pm wavelength resolution. RC-GPD arrays, assembled in flip-chip to ROIC arrays were packaged in a ceramic PGA with microlens arrays.

RC-GPD+ROIC arrays were tested at only 20 MHz for heat dissipation reasons. The total power consumption at 20MHz and RC-GPD biased at 1KHz dark count rate /pixel was 2W, with negligible contribution from the RC-GPD array. The AQC design was tested to allow stable operation up to 1V above the breakdown voltage. All design functions (APC, UP/DOWN/READ were verified to work. The product GainxQuantum efficiency at the resonant wavelength was 17%.

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9114-14, Session 4

SWIR Geiger-mode APD detectors and cameras for 3D imaging

Mark A. Itzler, Princeton Lightwave, Inc. (United States)

The operation of avalanche photodiodes in Geiger mode by arming these detectors above their breakdown voltage provides high-performance single photon detection in a robust solid-state device platform. Moreover, these devices are ideally suited for integration into large format focal plane arrays enabling single photon imaging. We report recent advances for the performance of both discrete and arrayed formats of InGaAsP-based Geiger-mode avalanche photodiodes (GmAPDs). In particular, through the reduction of the detector active region volume, we have realized significant improvement in detector characteristics such as dark count rate and radiation tolerance.

9114-15, Session 5

Advanced 3D imaging lidar concepts for long range sensing *(Invited Paper)*

Robert A. Lamb, Philip A. Hiskett, Gerald J. Wong, Karen J. Gordon, Agata M. Pawlikowska, Roger Pilkington, Peter Sinclair, SELEX ES Ltd. (United Kingdom)

Recent developments in 3D imaging lidar are presented. Long range 3D imaging using photon counting is now a possibility, offering a low-cost approach to integrated remote sensing with step changing advantages in size, weight and power compared to conventional analogue active imaging technology. We report results using a Geiger-mode array for time-of-flight, single photon counting lidar for depth profiling and determination of the shape and size of tree canopies and distributed surface reflections at a range of 9km, with 4 micro Joule pulses, a frame rate of 100kHz and a low-cost fibre laser operating at a wavelength of 1.5 microns. The range resolution is less than 4cm providing very high depth resolution for target identification. This specification opens up several additional functionalities for advanced lidar, for example: absolute rangefinding and depth profiling for long range identification, optical communications, turbulence sensing and time-of-flight spectroscopy. Complementary developments in computational imaging schemes for passive polarimetric and multispectral imaging will also be reported. Future concepts for 3D time-of-flight polarimetric and multispectral imaging lidar with optical communications, in a single integrated system are proposed. This multi-functionality will revolutionise future air-to-ground remote sensing for unmanned air vehicles.

9114-16, Session 5

Moderate to high altitude, single photon sensitive, 3D imaging lidars

John J. Degnan, Christopher T. Field, Sigma Space Corp. (United States)

Over the last several years, Sigma Space Corporation has developed a variety of scanning, single photon sensitive (photon-counting) 3D imaging lidars that operate at aircraft AGLs between 2 and 9 km (6 to 30 kft) with speeds in excess of 200 knots. All of these systems use a Diffractive Optical Element (DOE) to generate a 10x10 array of low power beamlets from a single laser beam which are then imaged by the receiver onto a matching 10x10 detector array, which feeds into 100 independent timing channels having a +40 psec (+6mm) timing/range resolution and a channel recovery time of less than 2 nsec . Thus, with laser repetition rates between 20 and 32 kHz, we have achieved measurement rates up to 3.2 million 3D pixels per second. High range resolution has been achieved through the use of laser pulsewidths between 100 and 700 picoseconds. The result has been rapid areal coverage with high resolution horizontal (few decimeter) and vertical (few centimeter) 3D imagery. Our systems are presently being deployed on a variety of aircraft to demonstrate their utility in multiple applications including large scale surveying and surveillance, bathymetry, forestry, etc. Our smallest unit , the Mini-ATM (Miniature Airborne Topographic Mapper) , designed for NASA to fit in a mini-UAV for wide swath cryospheric measurements, features a 90o full conical scan, measures approximately 0.03 m3 (1 ft3) in volume, weighs 12.7 kg (28 lbs), and consumes ~168 W of 28 VDC prime power.

9114-17, Session 5

Long range 3D imaging with a 32x32 Geiger mode InGaAs/InP camera

Philip A. Hiskett, Karen J. Gordon, Jeremy W. Copley, Roger Pilkington, Agata M. Pawlikowska, Peter Sinclair, Iain A. Clark, Robert A. Lamb, SELEX ES Ltd. (United Kingdom)

We report on the performance of a 3D imaging system for long range remote sensing operating at a wavelength of 1550nm which uses a photon-counting Geiger mode 32x32 InGaAs/InP camera. Pattern recognition techniques are used to mitigate range aliasing and enable the measurement of the absolute time-of-flight and therefore absolute range at very high frame rate, typically 125kHz. The imaging system is able to determine absolute range to single or multiple surfaces and derive depth profiles of distributed surfaces through clutter within the instantaneous field of view of each pixel. The performance of the photon-counting camera will be discussed for two alternative laser sources: a fast unamplified semiconductor diode laser with a data rate in excess of 40Mb/s at pulse energies of less than 10pJ per pulse and an optically amplified fibre laser at a data rate of 125kb/s with pulse energies of 4μJ per pulse. The performance of the system for measurements of the time-of-flight to remote manmade Lambertian surfaces and foliage at ranges up to 10km with range accuracy of better than 4cm are reported. These manmade Lambertian surfaces include buildings, motor vehicles and calibrated painted wooden boards. The simultaneous imaging and measurement of the time-of-flight of two remote manmade Lambertian surfaces separated by >1km will be also be presented.

9114-18, Session 5

Applications of depth imaging based on time-correlated single-photon counting *(Invited Paper)*

Gerald S. Buller, Aongus McCarthy, Ximing Ren, Nathan R. Gemmell, Aurora Maccarone, Yvan R. Petillot, Andrew M. Wallace, Heriot-Watt Univ. (United Kingdom)

Single-photon detection has emerged in recent years as a candidate for a number of depth imaging applications. This presentation will describe a series of proof-of-concept experiments which highlight the virtues of the approach, including sensitivity, accuracy and resolution, long range and eye-safe capabilities. At long distances, both superconducting and semiconductor-based single-photon detectors have been used to utilize atmospheric window around the 1550nm wavelength. We will discuss the merits of both detector types and the choice of this detector band. Another area of emerging interest is the use of multiple wavelength single-photon LIDAR which, for example, may be suitable for investigation of distributed targets. An appropriate selection of wavelengths can reveal indications of the structural and physiological parameters of vegetation. For example, the Normalised Difference Vegetation Index (NDVI) and Photochemical Reflectance Index (PRI) can be ascertained throughout the volume of the foliage, ultimately to provide a valuable insight into the carbon dioxide cycle for environmental research. We demonstrate early measurements and analysis from a prototype multiple wavelength system. Another growing area of interest is the use of single-photon depth imaging in turbid media. We present some preliminary results on underwater depth imaging, and illustrate the issues and challenges involved in the measurement of long-distance depth images in this environment.

9114-19, Session 5

Using HgCdTe e-APD detector arrays with single photon sensitivity for space lidar

Xiaoli Sun, James B. Abshire, NASA Goddard Space Flight Ctr. (United States); Jeffrey D. Beck, DRS RSTA, Inc. (United States)

We have recently developed a multi-element HgCdTe electron initiated avalanche photodiode (e-APD) focal plane array (FPA). The detector array was fabricated with 4.3μm cutoff HgCdTe with a spectral response from 0.4 to 4.3 μm. We have demonstrated a 4x4 e-APD FPA, with 80 μm square elements, followed by a custom CMOS read-out integrated circuit (ROIC). The device operates at 77K inside a small closed-cycle cooler-Dewar, and the support electronics integrated in a field programmable gate array (FPGA). Measurements showed a unity gain quantum efficiency of 91% at 1.5-1.6 μm wavelength. The bulk dark current of the HgCdTe e-APD at 77K

was less than 50,000 input referred electrons/s at 12 V APD bias where the APD gain was 620. The measured noise equivalent power (NEP) was 0.4 fW/Hz1/2. The rise and fall times of the response are about 50 nsec. These characteristics enable single photon detection at rates up to several MHz per pixel. Because the detector array operates in linear mode without avalanche breakdown, each pixel can count photons continuously without gating and have no dead-time. The present device allows considerable improvements in integrated path differential absorption (IPDA) lidar compared to near infrared photomultiplier tubes (PMT) and InGaAs APDs.

We are also developing a 2x8 FPA with similar HgCdTe e-APD but a much higher electrical bandwidth and lower input capacitance ROIC. The detector elements are designed for multiplication gains of 500-1000. The new FPA is optimized for laser altimetry and is expected give a much higher signal to noise ratio for single photon detection and better timing resolution. These new HgCdTe e-APDs will have wide application in space lidar from visible to mid-wave infrared (MWIR) wavelength and enable new scientific measurements with substantially less laser power.

9114-20, Session 6

New trends in silicon photomultiplier development *(Invited Paper)*

Valeri Saveliev, M. V. Keldysh Institute of Applied Mathematics (Russian Federation) and National Research Nuclear Univ. MEPhI (Russian Federation)

Single photon detection performance at room temperature is one of the fascination characteristic of the Silicon Photomultipliers (SiPM), shows the SiPM as an ultimate instrument for study of nature of photons and useful element in many applications as high energy physics, medical imaging systems, homeland security systems and other.

The detection principle of SiPM is based on the quantum nature of the electromagnetic radiation. In particular using the distributions of the radiation quanta in space and detection of the photon flux by submicron space distributed semiconductor micro-cells, sensitive to the single electromagnetic radiation quanta. The SiPM structure is based on the matrix of optically isolated submicron semiconductor micro-cells working in breakdown mode with integrated quenching elements and common electrode. All micro-cells are identical and independent provided high internal gain of amplification and allow detection up to single photon at room temperature. The common electrode structure gives these devices the possibility to acts as a proportional detector for measurement at ultra low intensity photon flux levels.

The interest to the Silicon Photomultipliers is dramatically increasing during last few years and few manufacturers are starting the mass production.

Nevertheless the potential of SiPM Structures is much high. The feature of SiPM is the digital nature of the principle of operation. The structure and material are compatible with Modern Microelectronics Technology. This open the way to getting the principle new structures (Sensor and Electronics on the same substrate) and organize the fully Digital Processing compatible with direct communication to the modern computing systems. The new trends in the development if the Digital Silicon Photomultiplier Structures will be presented.

9114-21, Session 6

Silicon photomultipliers for high-performance high-volume applications *(Invited Paper)*

Carlton Jackson, SensL (Ireland)

No Abstract Available

9114-22, Session 6

Study of silicon photomultipliers and applications

Nicola D'Ascenzo, Deutsches Elektronen-Synchrotron (Germany)

The interest in the Silicon Photomultipliers (SiPM) has been dramatically rising in the last few years. Nowadays the SiPM is substituting the conventional Photomultiplier Tubes and the other photodetectors for the low photon flux detection systems in many applications. In high-energy experimental physics the SiPM is already used in large scale prototypes for the new International Linear Collider project. Many studies are being performed for medical imaging systems with improved performance. SiPM-based systems have a very perspective application in homeland security infrastructure. The interest in SiPMs for optical telecommunications and optical interconnection systems is also growing.

The SiPM structure is based on an array of submicron semiconductor microcells, with a density of few thousands per mm2, working in breakdown mode with integrated quenching elements and common electrode. The microcells are identical and independent. Their internal gain of amplification is of the order of 10^5-10^6, allowing the detection down to the single photon at room temperature. The common electrode structure gives the possibility to act as a proportional detector for the measurement of the low intensity photon flux. The output is defined as the sum of the elementary uniform signals of the independent microcells triggered by the initial flux of photons.

A detailed mathematical simulation was developed for the optimization of the technological processes and the estimation of the performances for different applications, in particular for medical imaging systems. Results of the optimization and performance of the SiPM will be presented, with comparison between experimental tests and mathematical simulation.

9114-23, Session 6

Free-running operation of InGaAs single photon avalanche photodiodes with extremely low noise *(Invited Paper)*

Boris Korzh, Nino Walenta, Tommaso Lunghi, Raphael Houlmann, Claudio Barreiro, Hugo Zbinden, Univ. of Geneva (Switzerland)

Free-running single photon detectors at telecom wavelengths are attractive for many tasks in quantum optics. However, until recently, the convenient and compact InGaAs avalanche photodiodes did not operate with satisfactory performance in this regime due to high dark count rates and afterpulsing effects. The development of negative feedback avalanche photodiodes (NFAD) enabled very fast passive quenching of the avalanche current, effectively reducing the afterpulse probability and subsequently allowing free-running operation. Here we present recent analysis of NFAD operation at low temperatures, down to 150 K, which reveals a significant reduction of the dark count rate. We succeeded in developing a compact single photon detection system with a dark count rate of ~2 Hz at 10% detection efficiency. In order to ensure that the NFAD is in a well defined initial condition during the characterization of the detection efficiency and afterpulsing, we use a recently developed FPGA based test procedure suitable for free-running detectors. To demonstrate the performance of the detector in a real-world application we integrate it into a 1.25 GHz clocked, fiber-based quantum key distribution system. An optimization of the detector temperature allowed secret key distribution with more than 30 dB loss in the quantum channel.

9114-24, Session 7

Underwater optical communications at single photon sensitivities

Philip A. Hiskett, Robert Struthers, Roy Tatton, Robert A. Lamb, SELEX ES Ltd. (United Kingdom)

We present and discuss results for an optical communications system that uses photon counting to transmit and receive optical encoded data through water. The test system uses a laser diode operating at a wavelength of 450nm and an optical receiver containing a shallow junction silicon single photon avalanche diode. The optical data is transmitted through a 1m long aquarium tank containing ~100 litres of water. Optical attenuation due to scatter is varied by increasing the concentration of Maalox. A data transmission rate of 200kb/s through 74db of attenuation with a transmitted average power of 43uW was achieved. This is equivalent to ~ 4.7Mb/s/mW through 114m of clear sea water. The effect on the shape of the received optical pulse from scattering will also be discussed. Clock synchronisation between the transmitter and receiver channels is achieved using reference headers appended to the encoded message signal to correct for timing drift between the transmitter and receiver. The potential advantages of the use of single photon sensitive detection in the optical receiver system are described together with the engineering challenges encountered with the transmission of optically encoded data through water.

9114-26, Session 7

Receiver dead time in non-line-of-sight ultraviolet communications

Robert J. Drost, Paul L. Yu, U.S. Army Research Lab. (United States); Gang Chen, Univ. of California, Riverside (United States); Brian M. Sadler, U.S. Army Research Lab. (United States)

The significant scattering of deep ultraviolet (UV) light (e.g., 200-300 nm) by the atmosphere presents the possibility of non-line-of-sight (NLOS) optical communications, though a received NLOS UV signal can be expected to be greatly attenuated. Fortunately, absorption of nearly all solar deep-UV radiation by the atmosphere results in a virtually noiseless channel amenable to extremely sensitive photon-counting receivers. Much of the recent research on NLOS UV communications has focused on the use of rapidly maturing UV light-emitting diode technology for short-range (e.g., less than 100 m) communications. However, developments in solar-blind filter technology enabling such short-range communication also allow for longer range (e.g., 1-5 km) NLOS communication with a UV laser.

In addition to increased power output, UV lasers can transmit extremely short pulses, allowing for improvements in signal-to-noise ratios through gated-receiver designs. However, short transmitted laser pulses have the potential to overwhelm the response time of a practical receiver. After detecting a photon, a photon-counting receiver experiences a period of dead time during which subsequent impinging photons are ignored. The result is altered signal statistics and a communication-performance degradation that can be exacerbated if the altered statistics are not taken into account.

In this paper, we review and apply a Monte Carlo NLOS UV channel model to characterize system configurations for which the dead time of a typical photomultiplier tube can have significant effects. Results from a recent channel-sounding experiment are provided for real-world illustration of such effects. Finally, we contrast optimal detection algorithms with and without dead time effects and investigate performance implications associated with applying each algorithm in representative communication examples.

9114-27, Session 8

Advances in photon arrival timing circuitry and time-resolved luminescence imaging

Michael Wahl, Tino Roehlicke, Hans-Jürgen Rahn, Volker Buschmann, Uwe Ortmann, PicoQuant GmbH (Germany); Gerald Kell, Fachhochschule Brandenburg (Germany)

Progress in detector technology and growing interest in time-resolved detection methods in the materials and life sciences continues pushing the development of photon timing circuitry. While one early goal was the improvement of timing accuracy, some applications require other optimization targets. Notably in fast fluorescence imaging applications it is often more important to reduce dead time and increase throughput, matched to recent detectors such as hybrid photomultiplier tubes. Very good progress towards high timing resolution, short dead time and high throughput has recently been made with application specific circuits in Si:Ge technology. Compact and reasonably priced multichannel timing solutions have been designed this way and modern data bus technologies have helped to provide very high throughput in tima tagged data collection. When the requirements for time resolution are relatively low, when many detector channels are required and when ultimately short dead time is the top priority it can be more cost efficient to implement the entire timing system in field programmable logic. We present a modular system supporting both approaches and show the relative merits. Test results with special focus on data quality will be shown as well as results in some application examples, notably time-resolved luminescence imaging.

9114-28, Session 8

Effect of process parameters of CsI photocathode preparation in the enhancement of efficiency of gaseous photomultipliers

Baishali Garai, Indian Institute of Science (India); V. Radhakrishna, ISRO Satellite Ctr. (India); K. Rajanna, Indian Institute of Science (India)

There is a growing demand for large area photon detectors with sensitivity level of single photons for spectroscopy, astronomical imaging and high energy physics experiments. The detection efficiency of photon detectors such as gaseous photomultiplier (GPM) strongly depends on the photoemission property of photocathode and also the detection of photoelectrons emitted. In GPMs operating in the UV spectral range, a thin film of CsI coated over UV transparent quartz window acts as the photocathode. UV photons release photoelectrons into the gas volume of the detector; these photoelectrons undergo avalanche multiplications across electron multiplier structures producing large detectable signal. In this work, we have investigated the effect of different process parameters used during photocathode preparation on the photoelectron yield. It is found that if the substrate over which the CsI photocathode is deposited is subjected to in-situ plasma cleaning prior to deposition, the photoemission from the photocathode increases by 50-55 %. This effect is correlated with the microstructure of the deposited film studied under scanning electron microscope. Investigations also show that post deposition vacuum annealing of the film improves the photoemission and hence can lead to improved efficiency of the GPM. In addition, the rate of evaporation also plays a role in deciding the detectors efficiency. It is seen that a deposition rate of 1-2 nm/s gives better photoemission from the photocathode compared to higher evaporation rates.

9115-1, Session 1

Embeddable solid state fuel cells as power sources for autonomous systems *(Keynote Presentation)*

Shriram Ramanathan, Harvard School of Engineering and Applied Sciences (United States)

We will discuss our on-going efforts to realize ultra-thin solid oxide fuel cells with electrolytes at the electron tunneling limit. Such studies allow one to probe rigorously electronic-ionic transport in two-dimensional oxide membranes that are self-supported and proximal to free surfaces. Experimental realization of high performance two-dimensional solid oxide fuel cells operable in a variety of hydrogen and hydrocarbon fuels will be presented. By use of special oxide anode materials where in rapid redox processes occur at the operating temperature, one can realize energy storage as well, creating the ability to build-in additional functionality into existing solid state fuel cells. We will present select experimental case studies on this aspect as well using model vanadium oxide anodes. Experimental techniques to synthesize atomically tailored designer materials for electrolyte versus electrode graded functionality in thin film form in suspended structures will be considered. Integration of such micro-power sources into autonomous system structural components will be presented.

9115-2, Session 1

Development of irradiation methods and degradation modeling for state-of-the-art space solar cells *(Invited Paper)*

Takeshi Ohshima, Shin-ichiro Sato, Japan Atomic Energy Agency (Japan); Taishi Sumita, Tetsuya Nakamura, Mitsuru Imaizumi, Japan Aerospace Exploration Agency (Japan)

It is very important to understand the radiation response of solar cells since we need to predict the performance degradation of solar cells on space satellites during the missions. In general, the electrical characteristics of solar cells are evaluated before and after electron/proton irradiation, and accelerator facilities are just involved in irradiation (referred to as “Sequential method). Japan Atomic Energy Agency (JAEA) together with Japan Aerospace eXploration Agency (JAXA) has developed an in-situ evaluation technique that the electrical characteristics of solar cells can be measured under AM0 light illumination during proton/electron irradiation experiments (referred to as “Simultaneous method). As a result, we can shorten the evaluation period, since the Simultaneous method can allow us to know radiation degradation of solar cells during irradiation experiments. Furthermore, a sample holder with a cryogenic system was installed to the irradiation chamber in order to clarify the radiation response of solar cells under low temperature and low light intensity conditions such as missions for Mars or farther planet explorations. Using this unique method, we revealed the radiation degradation of multi-junction solar cells such as InGaP/GaAs/Ge triple junction (3J) solar cells under low temperature. In this paper, irradiation techniques for the evaluation of space solar cells will be introduced. The degradation mechanism of the 3J solar cells, and the modeling of degradation behavior of 3J solar cells will be also discussed. The development of space solar cells in Japan will be introduced, especially from the point of view of radiation response.

9115-3, Session 1

Tantalum tungsten alloy photonic crystals for high-temperature energy conversion

Veronika Stelmakh, Veronika Rinnerbauer, Jay J. Senkevich, Massachusetts Institute of Technology (United States); John D. Joannopoulos, MIT Institute for Soldier Nanotechnologies (United States); Marin Soljacic, Ivan Celanovic, Massachusetts Institute of Technology (United States)

A tantalum tungsten solid solution alloy, Ta 3%W, based 2D photonic crystal (PhC) was designed and fabricated for high-temperature energy conversion applications. Metallic PhCs are promising as high performance selective thermal emitters for solid-state thermal-to-electricity energy conversion concepts including thermophotovoltaic (TPV) energy conversion, as well as highly selective solar absorbers/emitters for solar thermal and solar TPV applications due to the ability to tune their spectral properties and achieve highly selective emission. The mechanical and thermal stability of the substrate was characterized as well as the optical properties of the fabricated PhC. The Ta 3%W alloy presents advantages compared to the non-alloys as it combines the better high-temperature thermo-mechanical properties of W with the more compliant material properties of Ta, allowing for a direct system integration path of the PhC as selective emitter/absorber into a spectrum of energy conversion systems. Furthermore, the thermo-mechanical properties can be fine-tuned by the W content. A 2D PhC was designed to have high spectral selectivity matched to the bandgap of a TPV cell, using numerical simulations and fabricated using standard semiconductor processes. The emittance of the Ta 3%W PhC was obtained from near-normal reflectance measurements at room temperature before and after annealing at 1200C for 24h in vacuum with a protective coating of 40nm HfO_2, showing high selectivity in agreement with simulations. SEM images of the cross section of the PhC prepared by FIB confirm the structural stability of the PhC after anneal, i.e. the coating effectively prevented structural degradation due to surface diffusion.

9115-4, Session 1

Doped semiconductor nanocrystals

Latha Nataraj, Aaron Jackson, Lily Giri, Clifford Hubbard, Mark L. Bundy, U.S. Army Research Lab. (United States)

Low-dimensional semiconductor structures such as nanocrystals are highly promising for various applications in electronics. The intentional addition of small amounts of foreign materials, known as dopants, provides an easy mechanism to control the behavior of semiconductors as their electronic, optical, and magnetic properties are considerably modified. Therefore, significant research is underway to explore the influence of dopants on semiconductor nanocrystals. Doped nanocrystals have been shown to provide better conductivity for thin conducting films, improved emission characteristics for lasers, protection for photovoltaic devices from photooxidation due to prolonged exposure, and serve as less harmful alternatives to toxic fluorescent dyes in bio-imaging, to name a few advantages. However, the process of doping such nanocrystals is extremely challenging due to their nanoscale sizes. In addition, the introduction of even a few atoms of the dopant into the nanocrystal that contains just a few hundred atoms could result in a degenerate material or compromise the crystal structure. Some strategies such as remote doping and substitutional doping have led to progress in acheiving doping in these nanocrystals and heavily doped nanocrystals have been obtained with p- and n-type dopants incorporated. However, such processes involve complex chemical synthesis processes and in some cases, do not provide consistently successful results. Many questions still remain unanswered. In this work, we present a simple, low-cost mechanism for consistently obtaining doped semiconductor nanocrystals through mechanical milling techniques and study their properties.

9115-5, Session 1

Nanocavity absorption enhancement towards atomically thin layers

Haomin Song, Kai Liu, Xie Zeng, Dengxin Ji, Nan Zhang, Qiaoqiang Gan, Univ. at Buffalo (United States)

In most thin-film energy harvesting/conversion applications, there is a long-existing trade-off between optical absorption and thickness of active materials. Particularly, research on two-dimensional (2D) atomic crystals and Van der Waals heterostructures receives intense efforts in recent years, which is promising for the development of new functional ultra-thin electronic and optoelectronic energy efficient devices, such as photodetectors, phototransistors and light sources. However, due to their atomically thin nature, the optical absorption is inherently weak. Consequently, absorption enhancement strategies will introduce revolutionary advances to these ultra-thin-film materials/devices. Here we propose a design by placing an ultra-thin absorptive material on top of a predesigned lossless spacer layer and a metal reflector to realize spectrally tunable resonances absorbed in the top ultra-thin layer. As the incident light is coupled into this structure, the reflected components will cancel the incident light at the top surface, resulting in a destructive interference absorber. Since the bottom metal reflector does not absorb much light, most energy will dissipate in the top ultra-thin layer resulting in the significant absorption enhancement. By tuning the thickness of the spacer layer, the destructive interference resonance is spectrally tunable for ultra-thin absorptive materials down to atomic thickness, and therefore overcoming the conflict between the optical absorption and film thickness of energy harvesting/conversion materials. This principle exploits the wave property of light in ultra-thin absorptive nanocavities and will pave the way towards the spectrally tunable absorption enhancement of ultra-thin materials including semiconductor films and monolayers of 2D atomic crystals.

9115-6, Session 2

High-efficiency energy harvesting using TAGS-85/half-Heusler thermoelectric devices *(Invited Paper)*

Gary E. Bulman, Bruce Cook, RTI International (United States)

RTI has combined two high-performance materials that have not previously been paired, to form a high ZT, hybrid thermoelectric (TE) device. We have employed a novel approach of combining enhanced “TAGS-85”, or e-TAGS, as the p-leg material, with improved half-Heusler (HH) materials for the n-leg, to raise the thermal-to-electrical conversion efficiency of waste exhaust at 750°C. This hybrid material pair takes advantage of recently-developed, high ZT modified TAGS alloys and n-type half-Heusler alloys to provide a high ZT, lead-free TE material solution for exhaust gas heat recovery for use in commercial or military vehicle platforms. RTI has developed the n-type half-Heusler alloys using a special high-energy milling approach to produce a reduced thermal conductivity, nanostructured bulk alloy. This approach included two novel elements to reduce thermal conductivity: (1) high-energy milling, and (2) addition of coherent inclusions. Single n-/p- couples were produced using eTAGS and half-Heusler pellets that achieved 9.2% efficiency with power output of 205mW for Thot = 559°C and ΔT = 523K. This compares to an all half-Heusler (p- and n-type) single couple which achieved 8.4% efficiency at Thot = 750°C and 7.5% at 600°C . This proof of concept demonstration clearly showed a dramatic efficiency improvement at a lower hot side temperature with the hybrid e-TAGS/HH single couple over the baseline HH couple. By optimizing the cross sectional areas of the pellets for equal heat flow, the resulting asymmetric couple achieved 10.5% efficiency with a maximum power output of 317 mW at Thot = 537°C and ΔT = 497°C. Based on these results, RTI has assembled a hybrid 49-couple module using p-type e-TAGS and n-type half-Heusler thermoelements and measured the performance of the hybrid module up to a maximum hot-side temperature of 600?C. The calculated device efficiency, corrected for radiation heat losses, reached a maximum of 10%. This result is noteworthy because modules consisting of an array of multiple n-/p- couples typically exhibit noticeably lower efficiency than the corresponding single couples under similar thermal profiles. The improved module efficiency is believed to be due to improved materials and optimized cross-sectional area ratios between the n- and p- elements.

9115-7, Session 2

MEMS electromagnetic energy harvesters with multiple resonances

Sudarshan R. Nelatury, Penn State Erie, The Behrend College (United States); Robert Gray, Penn State Harrisburg (United States)

There is going on a flurry of research activity in the development of efficient energy harvesters from all branches of energy conversion. The need for developing self-powered wireless sensors and actuators to be employed in unmanned combat vehicles also seems to grow steadily. These vehicles are inducted into perilous war zones for silent watch missions. Energy management is sometimes carried out using misson-aware energy expenditure strategies. Also, when there is a requirement for constant monitoring of events, the sensors and the subsystems of combat vehicles require energy harvesters that can operate over a discrete set of spot frequencies. This paper attempts to review some of the recent techniques and the energy harvesting devices based on electromagnetic and electromechanical principles. In particular, we shall delve into the design and performance of a MEMS-harvester that exhibits multiple resonances. Variation in the power density as a function of load is found, which determines the matched load resistance.

9115-8, Session 2

Piezoelectric-based event sensing and energy-harvesting power sources for thermal battery initiation in gun-fired munitions

Jahangir Rastegar, Omnitek Partners, LLC (United States); Carlos M. Pereira, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

A novel class of piezoelectric-based energy harvesting devices with integrated safety and firing setback event detection electronic circuitry that can be used in gun-fired munitions or other industrial equipment for detecting events such as impact or vibration or other similar events is presented. In this paper, the application of the device to the development of an initiation device for thermal reserve batteries in gun-fire munitions is presented. The novel and highly efficient electrical energy collection and storage and event detection and safety electronics used allows the use of a small piezoelectric element. As a result, such devices can be highly miniaturized. For thermal battery initiation, when the prescribed firing setback acceleration profile, i.e., the prescribed all-fire condition is detected, a highly efficient charge collection electronic circuitry would route the piezoelectric element generated charges to the initiator bridge element, thereby causing the thermal battery pyrotechnic material to be ignited. For munitions powered by thermal reserve batteries, the present initiation device provides a self-powered initiator with full no-fire safety circuitry for protection against accidental drops, transportation vibration, and other similar low amplitude accelerations and/or high amplitude but short duration acceleration events. The device is shown to be readily set to initiate thermal batteries under almost any all-fire conditions. The device can be readily hardened to withstand very high G firing setback accelerations in excess of 100,000 G and the harsh firing environment. The design of prototypes, including packaging for high-G hardening and results of their testing under realistic conditions are presented.

9115-9, Session 2

Large-scale lithography-free metasurface with spectrally tunable super absorption

Kai Liu, Xie Zeng, Dengxin Ji, Nan Zhang, Qiaoqiang Gan, Univ. at Buffalo (United States)

Plasmonic metamaterial super absorbers are attractive candidates for photo-harvesting, surface enhanced biosensing and photocatalysis. However, most reported meta-absorbers based on periodic nanopatterns were fabricated using expensive and low-throughput nano-lithography techniques [1,2], therefore imposing a serious cost barrier for the development of practical applications. Additionally, alternative methods such as chemical synthesis [3] and nanostencil lithography [4] are still difficult to obtain high-quality and large-area patterns. To overcome these limitations, here we report a simple, scalable and cost-effective method to manufacture uniform super absorptive metasurfaces using a direct sputtering technique. Using this technique, densely distributed metallic nanopatterns with controllable dimensions can easily be formed on either rigid or flexible substrates, which is compatible with large scale roll-to-roll processes. These metallic nanopatterns were then covered by an ultrathin dielectric film and optically-thick metallic ground plate sequentially to constitute a three-layered meta-absorber. A remarkable optical absorption peak over 96% in the visible regime was obtained successfully which is insensitive to polarization states and incident angles up to 70º. Moreover, the lateral dimension of these random nanopatterns can be tuned further by post thermal annealing processes, resulting in a wide spectral tunability of the super absorption resonances in the visible-to-near-infrared domain. This omnidirectional, polarization-insensitive super absorber structure is particularly promising for the development of novel thin-film energy harvesting devices, all-angle color filters and biomimetic photonic structures [5].

[1] Nano Lett. 10, 2342 (2010).

[2] APL 99, 253101 (2011).

[3] Nature 492, 86 (2012).

[4] APL 101, 151106 (2012).

[5] Adv. Mater. 22, 2939 (2010).

9115-10, Session 3

PV power plants production maximization *(Invited Paper)*

Andras Boross, SunEdison (United States)

Solar power plants provide an increasing percentage of our energy. This paper focuses on the power plants which use Photo Voltaic (PV) technology for power generation. Approximately 30 GW of solar power have been connected to the grid in the past few years. As of last year, the total installed solar power plants capacity has exceeded 100 GW. The lion share of this capacity is provided by utility (above 2.5 GW) and commercial (above 100kW) plants. Most of the PV planes are not run at optimum performance. If we, increase the yield by 1% without any additional investments we can provide additional energy to the scale of tens of additional utility scale plants. How can we maximize the yield?

Issues and Solutions:

- Soiling
- Equipment failure
- Curtailment
- Degradation
- Weather
- Shading, weeds
- Wrong reference data (pyranometer)

The issues listed above can create energy loss compared to the estimated or expected generated energy. This paper will examine all of these issues and offer one or more solutions for them. The fundamental goal is to produce more energy without additional overall cost or maintenance cost, which should be less than the revenue created by the additional energy produced.

All of the improvements are based on a well planned and executed monitoring of the plant. The required information for the optimum operation is available from the installed devices. The data collected is processed and analyzed in pseudo real-time on site and/or sent to a remote datacenter.

9115-11, Session 3

Printed vibration based energy scavenging and storage devices for mobile electronics

Kate J. Duncan, Victoria Carey, Mark S. Mirotznik, Univ. of Delaware (United States)

A self-powered system that scavenges energy from the body is attractive for sensing, personal electronics and wireless technologies. Thermal and mechanical (respiration, blood pressure, body movement) energies are possible and can be scavenged to power devices carried by most people and will require an accumulation circuit. We will present a simple, printed piezoelectric energy scavenger that converts vibrations into energy using piezoelectric polymers printed onto flexible substrates. Typically, the energy produced by piezoelectric scavengers is too small to directly power devices, so a charging circuit has been constructed to accumulate a sufficient amount of energy, powering the mobile electronics. The design of the energy-harvesting circuits allows for capturing and transferring intermittent low-energy bursts to the battery.

9115-12, Session 3

Integrated soldier power and data system (ISPDS)

Roman P. Ostroumov, Mohamad Zahzah, Thomas C. Forrester, Robert Stevens, Anthony Lai, Physical Optics Corp. (United States)

Physical Optics Corporation (POC) developed the body-worn Integrated Soldier Power and Data System (ISPDS), a configurable node for plug-in wired or wireless server/client or peer-to-peer computing with accommodation for power, sensor I/O interfaces and energy harvesting. The enabling technology increases uniformed personnel and first responders capability and provides an option for reducing force structure associated with the need for hardware network infrastructure to enable a mobile digital communications architecture for dismounted troops. The ISPDS system addresses the DoD's need for an "intelligent" power control system in an effort to increase mission duration and maximize the first responders and warfighter's effectiveness without concern for the available energy resources (i.e., batteries). ISPDS maximizes durability and survivability, assesses influences that affect performance, and provides the network backbone and mobile node hardware. POC is producing two vest-integrated variants, one each for U.S. Army PEO Ground Soldier and Air Soldier, with each including state-of-the-art low-profile and robust wearable connectors, cabling, and harnesses and an integrated low-profile power manager and conformal battery for data and power distribution. The innovative intelligent power controller (IPC), in the form of the ISPDS firmware and power sensing and control electronics, will enable ISPDS to optimize power levels both automatically and in accordance with manually set preferences. IPC module is power dense, efficient and adaptively provides lossless transfer of available harvested photovoltaic energy to the battery. The integrated systems were tested for suitable electrical, electromagnetic interference (EMI), and environmental performance as dictated by military standards such as MIL-STD-810G and MIL STD-461F.

9115-13, Session 3

Broadband absorption engineering of hyperbolic metafilm patterns

Dengxin Ji, Haomin Song, Xie Zeng, Haifeng Hu, Kai Liu, Nan Zhang, Qiaoqiang Gan, Univ. at Buffalo (United States)

Thin-film perfect absorbers are important optical/thermal components required by a variety of on-chip applications, including photon/thermal-harvesting, thermal energy recycling, and vacuum heat liberation. Recently, researches on metal-insulator-metal (MIM) metamaterials based perfect absorber and trapped "rainbow" storage of light have attracted considerable interests. However, these researches are limited by either narrow absorption band or relatively low coupling efficiency. In this work, we experimentally realize a patterned hyperbolic meta-film with engineered and freely tunable absorption band from near-IR to mid-IR spectral regions based on multilayered metal/dielectric hyperbolic metamaterial (HMM) waveguide taper. By cascading resonant MIM perfect absorber elements with gradually tuned widths along the vertical direction, the absorption band of the patterned HMM film is extended significantly. As the incident light is coupled into the HMM waveguide taper, the group velocity of the waveguide mode at different wavelength can be reduced significantly at their corresponding critical widths, resulting in the enhanced light-matter interaction [1]. In addition, multi-patterned HMM metafilms is also demonstrated to reduce the required number of metal/dielectric layers, and therefore simplifying the sample preparation and experimental realization of on-chip broadband super absorbers. The ability to efficiently produce broadband, highly confined and localized optical fields on a chip is expected to create new regimes of optical/thermal physics, which holds promise for impacting a broad range of energy technologies ranging from photovoltaics, to thin-film thermal absorbers/emitters, to optical-chemical energy harvesting.

Reference

[1] Hu, H., et.al. Rainbow Trapping in Hyperbolic Metamaterial Waveguide. Sci. Rep. 3, 1249 (2013).

9115-14, Session 3

High-voltage thin-absorber photovoltaic device structures for efficient energy harvesting *(Invited Paper)*

Roger E. Welser, Gopal G. Pethuraja, John W. Zeller, Ashok K. Sood, Magnolia Optical Technologies, Inc. (United States) and Magnolia Solar, Inc. (United States); Kimberly A. Sablon, U.S. Army Research Lab. (United States); Nibir K. Dhar, Defense Advanced Research Projects Agency (United States)

Efficient photovoltaic energy harvesting requires device structures capable of absorbing a wide spectrum of incident radiation and extracting the photogenerated carriers at high voltages. In this paper, we review the impact of active layer thickness on the voltage performance of both nano-enhanced III-V and conventional copper indium gallium diselenide (CIGS) photovoltaic device structures. We observe that thin absorber structures can, in some cases, be leveraged to increase the operating voltage of energy harvesting devices. Thin absorbers in combination with advanced light trapping structures provide an exciting pathway for enhancing the performance of flexible, lightweight photovoltaic modules suitable for mobile and portable power applications.

The output voltage of photovoltaic energy harvesting devices is governed by the underlying diode dark current. Theoretically, both the radiative and non-radiative components of the dark current can be reduced by minimizing the active layer thickness. In this work, recently reported experimental data from both III-V and CIGS cells is reviewed, confirming the expected trend of increasing open circuit voltage with decreasing active layer thickness. Analysis of recent work in the field of nano-enhanced absorbers also allows us to experimentally quantify the limiting radiative regime of operation. Advanced optical designs are then considered: designs that are compatible with flexible and lightweight photovoltaic modules for mobile and portable power applications.

9115-15, Session 4

Micro battery development: from fundamental research to manufacturing *(Invited Paper)*

Jie Xiao, Honghao Chen, Samuel Cartmell, Qiang Wang, Terence Lozano, Thomas Carlson, Zhiqun Deng, Pacific Northwest National Lab. (United States)

The Juvenile Salmon Acoustic Telemetry System (JSATS) project supported by the U.S. Army Corps of Engineers, Portland District, has yielded the smallest micro-acoustic transmitter commercially available to date. To study smaller fish and permit implantation by injection using a needle, the JSATS micro-acoustic transmitter was reduced in weight and volume. This study focuses on the development of micro-battery design based on lithium/carbon monofluoride (Li/CF_x with x = 1) chemistry. A steady high-rate pulse current with required lifetime was achieved while the weight and volume of the battery was significantly reduced. The newly designed micro-batteries have intrinsically lower impedance than the batteries currently used in JSATS transmitters, leading to significantly improved electrochemical performances within a wide operating temperature range from -5°C to 25°C. The fundamental science related with fluorination chemistry will also be discussed to tune the power/energy ratio for various requirements for practical applications.

9115-16, Session 4

Electrodics: mesoscale physicochemical interactions in lithium-ion batteries *(Invited Paper)*

Partha P. Mukherjee, Texas A&M Univ. (United States)

Recent years have witnessed an explosion of interest and research endeavor in lithium-ion batteries to enable vehicle electrification. In particular, a critical imperative is to accelerate innovation for improved performance, life and safety of lithium-ion batteries for electric drive vehicles. Lithium ion batteries are complex, dynamical systems which include a multitude of coupled physicochemical processes encompassing electronic/ionic/diffusive transport in solid/electrolyte phases, electrochemical and phase change reactions and diffusion induced stress generation in multi-scale porous electrode microstructures. While innovations in nanomaterials and nanostructures have spurred the recent advancements, fundamental understanding of the electrode processing – microstructure – performance interplay is of paramount importance. In this presentation, mesoscale physicochemical interactions in lithium-ion battery electrodes will be elucidated.

9115-17, Session 4

Tritium power source for long-lived sensors

M. Litz, U.S. Army Research Lab. (United States); D. C. Katsis, Athena Energy Corp. (United States); J. A. Russo, D. A. Burns, J. J. Carroll, U.S. Army Research Lab. (United States)

Isotope power supplies offer solutions for long-lived (100 yr), low-power (100uW) energy sources. The energy density of nuclear batteries uniquely serves applications for sensors or communications nodes that are required to last the lifetime of infrastructure. Efficiencies less than 10% are typical in direct-energy-conversion (DEC) of radiation to electric current, which is comparable to thermo-electrics (TE) and thermo-photo-voltaics (TPV). For low-power applications, avoiding a heat-cycle (Carnot limitation) is useful in reducing a heat signature. A beta-source is coupled directly to a

semiconductor (or includes a phosphor/optical conversion precursor) for conversion to free-electrons creating current in an electrical load. A low-cost approach is described for next-generation compact electronics and sensor applications.

9115-18, Session 4

Measuring battery state of health through mechanical stress measurements *(Invited Paper)*

John Cannarella, Craig B. Arnold, Princeton Univ. (United States)

The determination of a battery's state of health and state of charge is critical for the management of any energy storage system employing batteries (e.g. electric vehicles, grid storage, consumer electronics, etc.) Despite the fundamental importance of the SOH and SOC parameters in battery systems, determination of these parameters is not straightforward and remains an area of active research. We propose a novel method of SOH/SOC determination using easy measurements of stack pressure in battery cells. Using a model system containing a commercial lithium-ion pouch cell, we show that cell expansion is predictably related to both the SOH and SOC of a battery cell. We then show how these relationships can be used in a battery management system to continuously monitor the SOH and SOC of a battery cell during operation. The inherent simplicity of the proposed mechanical measurement system of battery management offers many advantages to the complex parameter estimation systems that comprise the current state of the art.

9115-19, Session 4

Design and fabrication of Li-ion microbatteries *(Invited Paper)*

Shen J. Dillon, Univ. of Illinois at Urbana-Champaign (United States)

Scaling conventional Li-ion battery electrodes to the microscale presents a number of challenges associated with electrode fabrication and battery packaging. Microscale batteries (volume < 1 mm3) often contain large volume fractions of inactive material that diminish the overall energy density. Alternative approaches deviate significantly from traditional electrode and system designs, and typically employ some type of top-down or bottom-up nanostructuring approach. This talk will detail our recent efforts for fabricate high energy density Li-ion microbatteries using direct ink writing and nanowire growth processes. The talk will also discuss packaging strategies, concepts for device integration, and cycling stability.

9115-20, Session 5

Flexible Li-ion battery electrodes prepared from nanostructured polymer-derived ceramic composites *(Invited Paper)*

Gurpreet Singh, Kansas State Univ. (United States)

We demonstrate synthesis and electrochemical performance of novel molecular precursor-derived ceramic (PDC)/carbon nanotube embedded graphene self-supporting composite papers as Li-ion battery electrode. The papers were prepared through vacuum filtration of various PDC-graphene oxide (GO) dispersions in DI water followed by thermal reduction at elevated temperatures that resulted in a homogenous PDC/reduced GO papers that were highly crumpled, mechanically robust and consisted of a 3-D electrically conducting network. Li-ion battery electrodes (prepared at a loading of ~ 1.0 mg/cm^2) showed stable charge capacity of approx. 500 mAh/g (w.r.t. total electrode weight) with nearly 100 % coulombic efficiency for 1000 cycles. Further, the post electrochemical imaging of the dissembled cells showed no apparent damage to the anode surface, highlighting improved chemical and mechanical stability of these ceramic composites.

9115-21, Session 5

Local electromechanical characterization of flexible nanostructured supercapacitors using atomic force microscopy

Daniel P. Cole, Kenneth E. Strawhecker, Mark L. Bundy, U.S. Army Research Lab. (United States)

Electric double layer capacitors (EDLCs), or 'supercapacitors,' store energy at the double layer interface between the electrode and electrolyte. EDLCs have relatively high specific power compared to batteries and fuel cells, and are expected to play an important role in hybrid energy storage and delivery systems for future vehicles and portable electronics. Carbon nanotubes (CNTs) offer excellent electrical properties, high chemical stability, and high specific surface areas, which are all desirable properties for EDLC electrode materials. In addition, CNTs possess high mechanical properties, making CNT-based EDLCs attractive for multifunctional structural-energy storage applications. In this work, solid state electrodes were processed by infiltrating a solid polymer electrolyte into an aligned CNT network. Flexible EDLCs were created by combining the composite electrodes with a conductive polymer current collector. The local morphology and mechanical behavior of the electrode/electrolyte interface was characterized using atomic force microscopy (AFM). Nanoscale capacitive behavior of the materials was studied using conductive AFM. The local electromechanical behavior of the composite electrodes is compared to the global behavior in order to better understand bulk material performance.

9115-22, Session 5

Nanoengineered capacitor materials with colossal dielectric constant

Narsingh B. Singh, Samuel Opeka, Vishnu Razdan, Marcus Zupan, Carlos A. Romero-Talamas, Univ. of Maryland, Baltimore County (United States)

The limitation of a well-publicized CaCu3Ti4O12 (CCTO) material [1-5] is the leakage current. CCTO is an excellent material with permittivity of 105 but material uniformity, charge compensation, and design of composite structures are limiting the applications. The status of leakage current measurements in CCTO, expressed as a conductivity or resistivity, is in the range of 106 ?-cm. A range of the resistivity values have been reported based on the processing conditions of the materials. All these values are reasonably lower than an ideal value needed for practical applications. The main objective for an R?C hold time requires a resistivity of about 1011 ?-cm. To overcome this problem, we have performed synthesis and growth of substituted CaCu3Ti4O12 (CCTO) to achieve large size homogeneous grains in different thermal conditions. We have used Aluminum and Si to achieve CaCu3AlxTi4-xO12 (CCATO) composition. Preliminary results indicate that resistivity was 2-3 order magnitude higher than pure CCTO material.

9115-23, Session 5

Nanostructured metal-oxides for use as high power and energy density storage electrodes

Bilge Saruhan-Brings, G. C. Mondragón Rodríguez, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); Yakup Goenuellue, Univ. zu Köln (Germany)

Pseudo-capacitance is achieved by use of metal-oxides yielding faradaic reactions over redox couples. Capacitive charge-storage properties of mesoporous films made of complex metal-oxides preferably in core + shell architecture are superior to those of non-porous crystalline metal-oxides. RuO2 yields the highest energy densities however is not attractive for commercial use due to high cost. Other promising candidates are MnO2, Co2O3, NiO, etc. which need to be improved for achievement of long-term stability. As well as the electrode material, the type of electrolyte is important by the performance of a supercapacitor.

This work describes the fabrication and performance of mesoporous double oxides (MnCu, MnNi, MnCo, etc) in aqueous electrolytes. Thin films are deposited by sputtering technique on metallic foils, graphitic and carbon fibre substrates. Specific capacitance, energy and power densities are calculated and the role of electrolyte selection demonstrated. Moreover, electrode materials having an aligned nano-structural titania will be presented demonstrating intercalation introduced enhanced capacitance.

9115-24, Session Posters-Tuesday

Analysis of solar cell using the Lambert W function with Maple

Daniel Villegas, Univ. EAFIT (Colombia)

A study of solar cells took place by using Lambert W function based diode model. All calculations were made through computer algebra, having the software Maple a special place.

Current vs. Voltage graph corresponding to cells was obtained as a main result, so as diode's parameters values such as the series, shunt resistances and its constant.

Analytical results will be useful for cell manufacturing, either for home or industrial usage.

As a future research line, Lambert W function utilization is suggested as a mean for multidiode systems development.

9115-26, Session Posters-Tuesday

Single stage AC-DC converter for Galfenol-based micro-power energy harvesters

Peyton Cavaroc, Chandra V. Curtis, Space and Naval Warfare Systems Ctr. Atlantic (United States); James P. Cooper, Middle Tennessee State Univ. (United States); Suketu Naik, Space and Naval Warfare Systems Command (United States)

Military based sensor systems are often hindered in operational deployment and/or other capabilities due to limitations in their energy storage elements. Typically operating from lithium based batteries, there is a finite amount of stored energy which the sensor can use to collect and transmit data. As a result, the sensors have reduced sensing and transmission rates. However, coupled with the latest advancements in energy harvesting, these sensors could potentially run indefinitely. Working with the magnetostrictive material Galfenol, we demonstrate the generation of enough energy to supplement and recharge a solid state battery, thereby overcoming the deficiencies faced by unattended sensors. As with any vibration-based energy harvester, this solution produces an alternating current which needs to be rectified and boosted to a level conducive to recharging the storage element. When operating down to the micro-watt level, power converter efficiency plays a critical role in the effective implementation of an energy harvesting source. The power converter and control circuitry must operate at ultra low power levels to minimize the parasitic losses they impose not only on the energy harvester, but potentially the storage element as well. This paper presents a power converter capable of efficiently converting an ultra-low AC voltage to a solid state charging voltage of 4.1V DC. While we are working with Galfenol transducers as our energy source, this converter may also be applied with any AC producing energy harvester, particularly at operating levels less than 2mW and 200mV AC.

9115-27, Session Posters-Tuesday

Junctionless thin-film ferroelectric oxides for photovoltaic energy production

Farnood K. Rezaie, Janardan Nath, Evan M. Smith, Univ. of Central Florida (United States); Isaiah O. Oladeji, SISOM Thin Films, LLC (United States); Robert E. Peale, Univ. of Central Florida (United States)

Streaming Process for Electrode-less Electrochemical Deposition (SPEED) method is used to create TiO_2/NiO thin films for photocatalytic water splitting. When codeposited, the two materials appear to segregate, with NiO serving as a matrix for ropy or vascular structures of TiO_2 that provide large active surface areas. The morphology, composition, crystallinity, UV spectrum, and hydrogen production rate are reported. That NiO and TiO_2 are semiconductors that form pn junctions retard the recombination of photo-excited electrons and holes.

9115-28, Session Posters-Tuesday

Modeling of high-efficiency ITO/ZnO quantum wire photovoltaic

Fahad A. Althowibi, Eric Donkor, Univ. of Connecticut (United States)

Photovoltaic, PV, cell is widely used for solar energy conversion and its technology is intensively studies and the research in this area is undergoing. Finding low-cost materials for PV cells and gaining high efficiency of sunlight-electric conversion are a challenge task to achieve. This paper presents a new nanofiber photovoltaic cell with ITO/ZnO/ITO concentric core, where ZnO serves as active medium for photogenerated carriers, and is designed to have higher efficiency of solar energy conversion. The high energy band gap and high refractive index of ZnO relatively to ITO generate high load voltage at cell terminals while fiber geometry contributes to increase current generation and charge separation. Results shows that the open voltage records 3.4V, and the short-circuit current ranges between 0.2A to 3.5A both of which are function of the nanofiber optical and electronic constituent parameters, as well as device geometry.

9115-29, Session Posters-Tuesday

Designing a concentrating photovoltaic (CPV) system in adjunct with a silicon photovoltaic panel for a solar competition car

Andrés Arias-Rosales, Jorge A. Barrera-Velásquez, Gilberto Osorio-Gómez, Ricardo Mejía-Gutiérrez, Univ. EAFIT (Colombia)

Solar competition cars are a very interesting research laboratory for the development of new technologies heading to their further implementation in either commercial passenger vehicles or related applications. Besides, worldwide competitions allow the spreading of such ideas in a healthy academic environment, where the best and experienced teams bet on innovation and leading edge technologies, in order to develop vehicles that are more efficient. In these vehicles, some aspects make the difference just like aerodynamics, shape, weight, wheels and photovoltaic, since efficient electric motors and batteries are of common usage between all the competitors. In this way, the first Colombian solar vehicle, competitor at the World Solar Challenge 2013 in Australia, has implemented the usage of a Concentrating Photovoltaic (CPV) system as a complementary solar energy module to the common silicon photovoltaic panel implemented on the top of the vehicles. This system allows the use of more effective solar cells with lower areas concentrating solar radiation by lenses, but in this specific application, the weight induced by the CPV must be less harmful that the benefit of the usage of the whole system. Such design considerations and its implementation is presented in this document along with the different steps of the design process considering both the restrictions of the context and the interaction of the CPV system with the solar car setup. The measured data make evident the advantage of the usage of this system during the competition concerning the solar energy harvested with the main silicon photovoltaic panel.

9115-30, Session Posters-Tuesday

Can seismic (destructive) energy be stored after conversion into electrical or acoustic energy?

Umesh P. Verma, Madhurendra N. Sinha, Patna Science College (India)

"On The purview of precursory revolution in the seismology by Electromagnetic radiation theory and:F.T. Freund2010)et.al,basing piezoelectric effect on the crustal geo-materials emanation of seismic pre signals have been noted frequently. Theirs' effect in form of ULF and VHF are commonly detected (by Greece and American seismologists)in the upper ionosphere from surface of globe.TEC, OLR. MMC are the consequent instrumentation in acquiring data to these pre-earthquake signals. Our attempt is to detect the signals prior to earthquake due to impending stress in the area and store the spreading destructive energy in electrical voltage applying the mathematics of piezoelectric equations and algebra in this context imphasis over the application of piezoelectric sensors as smart structure in the circuit configuration can be implied for the detection of DC signals and thus harnessing process can be made by selecting simulation and modulation of seismic signals into DC voltage. Smart sensors of varying frequency –set graduated at different LB and Watt shaped in various configuration by MIDE Vulture application can be made.Though the task seems chalenge but with the available literature of works on American and Greece platform : F>.T .Freidemann.(NASA)and Afatxious et.al(2010,2011) can be cited in the this field as citation for Pre- seismic ELF/ULF/and ELS display confirming the electrical discharge generation.

9115-31, Session Posters-Tuesday

Procedure to determine module distribution within a solar array to increase the net energy collection in a solar competition vehicle

Nicolás Suárez-Castañeda, Ana M. Gil-Herrera, Jorge A. Barrera-Velásquez, Gilberto Osorio-Gómez, Ricardo Mejía-Gutiérrez, Univ. EAFIT (Colombia)

A solar panel installed on a solar competition vehicle is expected to collect as much solar radiation as possible, and transform it into electrical energy efficiently. Unlike a static photovoltaic array, a solar car is subjected to changes on incident radiation and constantly varying shades, which decrease the uptake of energy and, thus, its net efficiency. Various factors intervene in the position, size and time of appearance of shadows on the panel. Environmental factors (e.g. trees, buildings, mountains, etc.) that cannot be controlled will not be discussed in this paper. Since their variability can be avoided or reduced easily (in practical terms using the vehicle in environments with few sources of shadows, or where the time of exposure to these shadows is minimal, just as seen in desert road conditions with constant speed). Similarly, the spatial and temporal conditions cannot be controlled, with a global impact that significantly affects vehicle performance. They comprise conditions such as the time of day, terrestrial solar vehicle position, current season or solar cycle, just to name a few. Finally, there is a third set of intervening factors originating from the vehicle itself, such as the relative position of the panel to other elements (such as canopy, driver, panel curvature, etc. Since available space for installation of the panel is limited, it becomes difficult not to install solar modules in areas impacted by shadows, requiring the reduction of impact from these modules, on the overall vehicle generation. Shadow patterns arise from the relative position of the sun to the earth, and the relative position of the car towards both of them. Since car, earth and sun are moving in semi-predictable patterns, computer simulations can cross and match data from such sources to forecast generation behavior. The outputs of such simulations are shadow patterns on the surface of the vehicle, indicating locations that are suitable or unsuitable to install solar cells. This paper will show how this analysis was applied to the design of the solar panel for a Challenger Class solar vehicle that participated in the World Solar Challenge 2013. Illustrating how the employment of a computational tool can help in the acquisition of both qualitative and quantitative information, related to shadows position and their impact on panel collection. Using data inputs such as vehicle geometry and its relative position towards the route, the tool was used to evaluate different possible configurations and select the ones that are more convenient to the given scenario.

9115-32, Session Posters-Tuesday

Temperature influence on energy density of nanocomposite for dielectric capacitor

Mohammad Arif I. Shuvo, Md. Rajib, Hasanul Karim, Diego Delfin, Yirong Lin, The Univ. of Texas at El Paso (United States)

With the development of modern technology, the demand of high energy density dielectric capacitor devices is increasing for its significant role in stationary power systems, mobile devices and pulse power applications. Dielectric capacitor with high energy density at elevated operating temperature is one of the present research demands. $BaTiO_3$ (Barium titanate) and PVDF (Polyvinylidene fluoride) have higher energy density at elevated temperature and is strongly influenced by temperature. Barium titanate exhibits a significant change in dielectric properties at its Curie temperature 120°C, which has a great impact on energy density of dielectric capacitor. In this study we have fabricated $BaTiO_3$/PVDF nanocomposites with different volume fractions of ceramic filler materials by solution casting method to investigate their energy densities at temperature ranges from 20°C to 120°C. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) were used for materials characterization. Capacitance and breakdown strength were measured to determine the energy density of the samples with 10%, 20%, 30% and 40% volume fractions. Nano-composites with 30% volume fraction showed highest energy density of 5.79 J/cc at 50°C.

9115-33, Session Posters-Tuesday

Magnetohydrodynamic-based devices for energy harvesting from motion and vibration

John Vetrovec, Aqwest, LLC (United States)

We report on innovative magnetohydrodynamic (MHD)-based devices for harvesting of energy from motion and mechanical vibration. The Aqwest energy harvesters use an electrically conductive working fluid and permanent magnets to achieve very high conversion efficiencies of mechanical energy to electrical energy. This paper describes the physics, design, and testing of energy harvesters using this principle. MHD energy harvesters can be used to recover energy from mechanical vibrations (e.g., on vehicles) or to recuperate energy from reverse stroke of actuators. The former can find applications powering of remote sensors while the latter are aimed for recharging storage batteries of electric actuators.

9115-34, Session Posters-Tuesday

Pulsed wireless photonic power transfer at high irradiance

Harbans S. Dhadwal, Omnitek Partners, LLC (United States)

Photonic power conversion (PPC) uses high power laser diodes to deliver electrical power to remote locations, either through a guided approach using fiber optics or by beam propagation through the air. Photovoltaic cells, with peak wavelength response matched to the peak wavelength of the laser diode, provide high efficiency conversion by means of single junction devices, connected in series for the desired open circuit voltage. The short circuit current is proportional to the incident optical power. Continuous operation of these devices is usually restricted to an equivalent irradiance of 1000 suns and multiple devices can be configured in parallel provide the desired electrical power. Pulsed power transfer is more effective for applications, such as dormant sensors, which have sporadic need for electrical power. Such systems, however, require rapid dump of energy into the storage device, typically, a high capacity double layer capacitor. Current-voltage characteristics of the PPC are not a sufficient indicator of the performance of the device under different illumination conditions. It is necessary to study the behavior of the device for the intended use. Our measurements explore the feasibility of using PPC devices to replace thermal/inductive power sources inside a munition shell. In this paper, we explore optimal illumination conditions to minimize the charging time of a 25 F capacitor. Comparative data, for two types of commercial GaAs PPC devices, which have a peak response around 810 nm is presented. The first, has a diameter of 2 mm for use with a mutimode optical fiber, while the second, has large area photovoltaic converter suitable for long distance wireless transmission of power. Experimental results indicate that the surface irradiance and laser power both determine the minimum energy transfer time. We found that both devices operated at irradiance levels exceeding 13,000 suns without causing thermal damage to the PPC.

9116-1, Session 1

A haptic sensing upgrade for the current EOD robotic fleet *(Invited Paper)*

Patrick S. Rowe, RE2, Inc. (United States)

The past decade and a half has seen a tremendous rise in the use of mobile manipulator robotic platforms for bomb inspection and disposal, explosive ordnance disposal, and other extremely hazardous tasks in both military and civilian settings. Skilled operators are able to control these robotic vehicles in amazing ways given the very limited situational awareness obtained from a few on-board camera views. Future generations of robotic platforms will, no doubt, provide some sort of additional force or haptic sensory feedback to further enhance the operator's maneuvers with the robot, especially when dealing with fragile, unstable, and explosive objects. Unfortunately, the robot operators need this capability today. This paper discusses an approach to provide existing (and future) robotic mobile manipulator platforms, with which trained operators are already familiar and highly proficient, with this desired haptic and force feedback. The goals of this upgrade are to be rugged, reliable, and affordable. It should also be able to be applied to a wide range of existing robots with a wide variety of manipulator/gripper styles and sizes. Finally, the presentation of the information to the operator is also discussed, given the fact that control devices that physically interact with the operator are still in the research stages.

9116-2, Session 1

Tactile MEMS-based sensor for delicate microsurgery

Young Soo Park, Argonne National Lab. (United States); Woo Ho Lee, The Univ. of Texas at Arlington (United States); Nachappa Gopalsami, Argonne National Lab. (United States); Mohan S. Gundeti, The Univ. of Chicago Medical Ctr. (United States)

The incorporation of robotics in surgery has increased dramatically recently, owing to the advantages of shorter recuperation, minimal morbidity and better aesthetic appearance and ease of performing the intricate suturing. From the learning curves of operating with robots, however, the surgeons have realized that further improvements are required especially the haptic feedback. While there are many advances in haptic display, relatively little material is available for the essential haptic sensing. Haptic sensing is a complex mechanism perceived by various cutaneous mechanoreceptors - Merkel's discs (pressure), Pacinian corpuscles (vibration), Meissner's corpuscles (delicate touch, texture), Ruffini's ending (tension, stretch). While some sensors such as strain gauges and accelerometers are available for replicating some of these perceptions, most delicate sense of touch, equivalent to Meissner's corpuscle, is not replicated. To this end, we are developing a tactile sensor capable of replicating the human sense of delicate touch. To attain high spatial resolution required for mounting on surgical instrument tip, this paper presents a preliminary development of the MEMS-based tactile sensor development. The sensor element is designed in diaphragm form using SU-8 substrate and gold as piezoresistor. Sensor elements of various diaphragm sizes (300, 500, 700, and 900 um) are fabricated to allow wide range of stiffness measurement. The characteristic test indicated that the stiffness of the sensors elements match those of surgical tissues. Upon successful development, such a tactile sensor will be essential for delicate surgeries, such as handling delicate tissues and in microsurgery.

9116-3, Session 1

Tactile sensing and compliance in microstressbot assemblies

Vahid Faroutan, Ratul Majumdar, Igor Paprotny, Univ. of Illinois at Chicago (United States)

Microassembly is one of the applications successfully implemented by group of individually-controllable MEMS microrobots (MicroStressBots). Although the robots are controlled using a centralized optical closed-loop control systems, i.e., a camera mounted on top of a microscope, compliance and self-alignment were used to successfully reduce the control error and permit precise assembly of planar structures. In this work, we further explore the possibility of using compliance to facilitate docking between MicroStressBots. The forces generated by the docking surfaces create a local attractor (pre-image of the goal configuration) that facilitates alignment between the two structures. Through this interaction the robot senses and aligns its position to match the desired configuration.

Specifically, in this work we examine two cases: a) docking of two microrobots with straight front edges that promote sliding, and b) docking of two microrobots with patterned edges that restricted sliding between the two robots. In the former case, the robots are engaged in mutual alignment, which is akin to pairwise Self Assembly (SA). This allows generation of highly accurate seed-shapes for further assembly. In the latter case, the robots with matching pattern edges can dock and successfully align. Here, the patterned edge functions as a lock-and-key mechanism, and is akin to the selective affinity in SA-systems. The difference however between a system of MicroStressBots and SA however is that MicroStressBots have active propulsion and control, compared with passive SA systems.

9116-4, Session 1

Haptic exploration of fingertip-sized geometric features using a multimodal tactile sensor

Ruben D. Ponce Wong, Randall B. Hellman, Veronica J. Santos, Arizona State Univ. (United States)

Haptic perception remains a grand challenge for artificial hands. Dexterous manipulators could be enhanced by "haptic intelligence" that enables identification of objects and their features via touch alone. Haptic perception of local shape would be useful when vision is obstructed or when proprioceptive feedback is inadequate, as observed in this study. In this work, a robot hand outfitted with a deformable, bladder-type, multimodal tactile sensor was used to replay four human-inspired haptic "exploratory procedures" on fingertip-sized geometric features. The geometric features varied by type (bump, pit), curvature (planar, conical, spherical), and footprint dimension (1.25-20mm). Tactile signals generated by active fingertip motions were used to extract key parameters for use as inputs to supervised learning models. A support vector classifier estimated order of curvature while support vector regression models estimated footprint dimension (positive and negative values encoded bumps and pits, respectively). A distal-proximal stroke (along the long axis of the finger) enabled estimation of order of curvature with an accuracy of 97%. Curvature-specific regression models performed better than a single regression model for all orders of curvature, and yielded R2 values of at least 0.95. While a radial-ulnar stroke (along the short axis of the finger) was most helpful for estimating feature type and size for planar features, a rolling motion was most helpful for conical and spherical features. The ability to perceive local shape could be used to advance robot autonomy and provide haptic feedback to human teleoperators of devices ranging from bomb defusal robots to neuroprostheses.

9116-5, Session 2

Experimental testbed for robotic skin characterization and interaction control

Kyle Shook, Woo Ho Lee, Kamesh Subbarao, Dan Popa, The Univ. of Texas at Arlington (United States)

Currently robots are able to reliably perform repeated, specific tasks when

their movements are predefined and reside in structured environments. The next generation of robots will need to perform tasks in unstructured dynamic environments and in close collaboration with humans. This will require a vast increase in the robot's perception of its surroundings through improved sensors. We are working on robotic skin to create distributed sensors for touch, temperature, acceleration and proximity to humans. To test robotic skin prototypes we have built an experimental testbed to apply loading profiles on pressure sensors embedded in artificial skin in order to create reduced order models of skin sensors for simulation and control. Measurement data from the load applicator and embedded sensor is acquired using National Instruments real time control technology and used as input into MATLAB's System Identification Toolbox to obtain the desired models. With this setup many skin sensor designs undergoing a range of loading profiles can be tested and modeled.

9116-6, Session 2

Conformal grasping using feedback controlled bubble actuator array

Wei Carrigan, Manoj Mittal, Richard E. Stein, Muthu B. J. Wijesundara, The Univ. of Texas at Arlington (United States)

Current robotic end effectors (e.g. grippers and hands) have the ability to conformally grasp well-defined objects but are limited in their ability to effectively handle objects with disparate shapes and material properties. To enhance robotic manipulation capabilities, a novel dynamically controlled sensor-actuator layer is overlaid onto the end effector to act as an "active skin" component. The active skin is comprised of an array of omnidirectional silicone bubble actuators beneath an array of force sensors. Each bubble can be dynamically inflated or deflated to better conformally grasp the target object. Dynamic redistribution of bubble pressure allows the force acting upon the point of contact with the grasped object to be minimized without a corresponding increase in the degrees of freedom required by the end effector. Thus, enhanced grasp control can be achieved without increasing the complexity of the end effector. Through further development, this bubble actuator technology can also allow visual control system to ignore error in the generated object position and orientation because the object grasping is handled through the sensor actuator array and the end effector can be generally positioned near the object. In addition, bubble actuator technology can be applied to many human robot interactions including health care and service robots where safety and pressure loading of sensitive areas is a large concern.

9116-7, Session 2

Development and characterization of a new silicone/platine-based 2-DoF sensorized end-effector for micromanipulators

Xin Xu, Joel Agnus, Micky Rakotondrabe, FEMTO-ST (France)

This paper reports the development and the characterization of a new silicone end-effector with integrated sensor based on a set of platine piezoresistive gage. Used as interface between a micromanipulator and a manipulated small object, the features of the end-effector are: 1) its compactness (length between 750μm and 2mm, width=40μm, thickness=25μm), 1) the fully integrated force measurement system thanks to microfabricated platine piezoresistive gage, 2) the 2-dof (degrees of freedom: along y and z axis) measurement capability, 3) the high sensitivity of measurment provided for each axis (0.6% to 0.8% for the range of measured force of 1mN), 4) and the relatively high gauge factor (G=6). This paper reports the principle, the steps of microfabrication and the characterization of the 2-dof sensorized end-effector.

9116-8, Session 2

A multidirectional capacitive proximity sensor array

Jiang Long, Mitsubishi Electric Research Labs. (United States) and Univ. of California, San Diego (United States); Bingnan Wang, Mitsubishi Electric Research Labs. (United States)

Proximity sensors have many important applications in industrial automation, such as accurate position sensing, thickness measurement, and obstacle detection. In robotics, proximity sensors can detect the existence and distance of an obstacle in small range, where vision sensors have larger error. In order to cover a larger sensing area and achieve more accurate sensing, more than one sensor is needed. For sensing on a curved surface, multi-directional functionality is required for such sensors.

This paper presents a multi-directional capacitive proximity sensor array, with four elements designed to detect objects coming from four different directions. All sensor elements are realized with simple circular patch with similar dimension, and are modeled as tunable capacitors with capacitances vary according to the proximity of intruding objects. Such tunable capacitance is integrated into a quad-band band-stop filter, with four notches located at 140MHz, 180MHz, 240MHz and 340MHz. The band-stop filter is composed of four decoupled LC resonant circuits, so each stop band is determined by one capacitive sensor and its corresponding lumped inductor. Therefore, the change in capacitance can be obtained by measuring the change of the notches of the band-stop response. The filter is fabricated into a cubic shape for sensing different directions. Measurement results show distinct change of notch responses due to objects coming from different directions. The fabricated sensor can detect objects coming from all four directions simultaneously by measuring four frequencies near four notches. The measured sensing range for all directions is at least 8mm.

9116-9, Session 3

Need and emerging trends in remote sensing

Michael McNair, Jeongsik Shin, The Univ. of Texas at Arlington (United States)

From the earliest need to be able to see an enemy over a hill to sending semi-autonomous platforms with advanced sensor packages out into space, humans have wanted to know more about what is around them. Issues of distance are being minimized through advances in technology to the point where remote control of a sensor is useful but sensing by way of a non-collocated sensor is better.

We are not content to just sense what is physically nearby. However, it is not always practical or possible to move sensors to an area of interest; we must be able to sense at a distance. This requires not only new technologies but new approaches; our need to sense at a distance is ever changing with newer challenges. As a result, remote sensing is not limited to relocating a sensor but is expanded into possibly deducing or inferring from available information.

This paper presents an overview of remote sensing and explores the trends and directions into which this exciting area is moving. Based on today's technologies and tomorrow's needs, we also look at what the future might hold. Even so, it is not just the technology that is important: the cost of the technology and the cost of its use is vitally important for success. The trends before us will be shaped by available funding in spite of having the best sensing methods.

9116-10, Session 3

Toward controlling perturbations in robotic sensor networks

Ashis G. Banerjee, Saikat Ray-Majumder, GE Global Research (United States)

Robotic sensor networks (RSNs), which consist of networks of sensors placed on mobile robots, are being increasingly used for environment monitoring applications. In particular, a lot of work has been done on simultaneous localization and mapping of the robots, and optimal sensor placement for environment state estimation [1]. The deployment of RSNs, however, remains challenging in harsh environments where the RSNs have to deal with significant perturbations in the forms of wind gusts, turbulent water flows, sand storms, or blizzards that disrupt inter-robot communication and individual robot stability. Hence, there is a need to be able to control such perturbations and bring the networks to desirable states with stable nodes (robots) and minimal operational performance (environment sensing). Recent work has demonstrated the feasibility of controlling the non-linear dynamics in other communication networks like emergency management systems and power grids by introducing compensatory perturbations to restore network stability and operation [2]. In this paper, we develop a computational framework to investigate the usefulness of this approach for RSNs in marine environments. Preliminary analysis shows promising performance and identifies bounds on the original perturbations within which it is possible to control the networks.

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9116-11, Session 3

Advanced THz sensor array for precise position and material properties recognition

Aleksander Sešek, Janez Trontelj, Univ. of Ljubljana (Slovenia); Andrej Švigelj, Letrika Lab. d.o.o (Slovenia)

The precise position of objects in the industrial process, assembly lines, conveys or processing bins is essential for fast and high quality production. In many robotized setups the material type and its properties are crucial. When several types of materials or parts are used, material recognition is required. Advanced robotics systems depend on various sensors to recognize material properties and high resolution cameras with expensive laser measuring systems are used to determine the precise object position.

The purpose of this paper is to present how the THz sensor and THz waves can be applicable for such precise object position sensing and its material properties in the real time. One of additional features of such THz sensor array is also ability to see behind the barriers which are transparent for THz waves. This allows the system to obtain precise dimensions, position and material properties of the object, which is invisible for visible light or anyhow obscured to other vision systems. Furthermore, a 3D THz image of the object can also be obtained and, in cases when visual picture is available, its fusion with a THz image is possible.

In the paper a THz sensor array, operating at a 300GHz central frequency and at room conditions is presented, together with the proposed vision system description. The target is illuminated with frequency modulated solid state THz source, providing output power around 1mW. By mixing of illuminating and reflected signal, the resulting difference frequency signal is obtained. Its amplitude and phase carry all relevant information of the target. Some measurement results are also shown and discussed.

9116-12, Session 3

Micro-sensor selection for outdoor air quality monitoring

Kristen L. Dorsey, John Herr, Univ. of California, Berkeley (United States); F. S. Alleyne, U.S. Dept. of Agriculture (United States); Albert P. Pisano, Univ. of California, San Diego (United States)

Airborne pollutants pose a threat to health and the environment. Of these pollutants, <2.5 μm diameter particulate matter, NOx compounds, and ozone are of the greatest concern to both acute and chronic human health. Sensors that enable real-time air quality monitoring will aid in the identification of pollution sources and composition of pollution plumes and inform citizens of their exposure to pollutants.

One major impediment to pervasive air quality monitoring is the lack of sensors in urban neighborhoods. We propose an array of airborne pollutant sensor clusters stationed throughout an urban core (e.g., on streetlamps) that detect the location, composition, and source of pollutants (e.g. fires, dirty cars, buildings) and enable enhanced information for first responders and public safety officials. Sensor placement and required 20+ year lifespan demands that they withstand harsh urban environments.

We will demonstrate an air quality sensing cluster and characterize its performance in detecting ppm concentrations of ozone, NOx compounds, and particulate matter. The gases will be detected through a previously demonstrated micro-electro-chemical sensor. Particulate matter of diameters <10 μm, < 2.5 μm, and <1 μm will be detected with a system of filters and gravimetric sensors. A previously demonstrated Lamb mode resonator will be deployed as the particulate matter sensor. The sensor cluster will also be deployed in real-world environments to test its capabilities in distinguishing various urban environments.

9116-13, Session 3

Radiation detection based on luminescence ratio method

Wei Chen, Lun Ma, Rasool Kenarangui, Andrew Brandt, Erick Jones, Alex Weiss, The Univ. of Texas at Arlington (United States)

Fluorescence intensity ratio (FIR) is a reliable and sensitive technology in measurements using relative fluorescence intensity changes from two energy levels. It has important applications in thermometry, biological sensing, and trace water detection. However, FIR has been rarely applied for radiation detection. In this work, we prepared ZnS:Mn,Eu phosphor with two emissions for X-ray radiation doses measurement. The X-ray diffraction (XRD) shows that the obtained phosphor has both ZnS sphalerite and wurtzite phases. The transmission electron microscopy (TEM) study reveals that ZnS:Mn,Eu phosphors have large particles of microns and nanoparticles of about 20 nm. A very intense violet emission of 420 nm from ZnS:Mn,Eu is newly reported. The emission is related to Eu2+ doping but only appears at certain Eu2+ concentrations. More interesting, It is found that the intensity of the 420 nm violet fluorescence is X-ray does-dependent, while the red fluorescence of 583 nm due to the d-d transition of Mn ions is not. The FIR of the two emissions has been investigated and empirical formulas of X-ray radiation doses as a function of FIR are provided for radiation does measurement. Possible X-ray irradiation induced fluorescence quenching mechanisms are discussed. The intense emission not only provides a violet light for solid state lighting but also offers a very sensitive method for radiation detection.

9116-14, Session 4

EHD printing as sensor fabrication technology for robotic skins

Jeongsik Shin, Woo Ho Lee, Caleb Nothnagle, Muthu B. J. Wijesundara, The Univ. of Texas at Arlington (United States)

Human-robot interaction can be made more sophisticated and intuitive if the entire body of a robot is covered with a multi-modal sensors embedded in artificial skin. In order to efficiently interact with humans in unstructured environments, robotic skin may require sensors such as touch, impact, and proximity. Integration of various types of sensors into robotic skin is challenging due to the topographical nature of skin. Printing is a promising technology that can be explored for sensor integration as it may allow both sensors and interconnects to be directly printed into the skin. We are developing Electrohydrodynamic (EHD) ink jet printing technology in order to co-fabricate various devices onto a single substrate. Using strong applied electrostatic forces, EHD allows the printing of microscale features from a wide array of materials with viscosity ranging from 100 to 1000Cps, highly beneficial for multilateral integration. This paper will present preliminary data on printing metal oxide microstructures intended for gas sensors as well as patterning of gold on various substrates using EHD as a mask-less lithography method. Thus far we have obtained ZnO structures with linewidths of 18 to 65 microns within a thickness of 33 to 65nm using custom inks. For the gold patterning, we have obtained linewidths of 14 microns and above. In these experiments, we have used an array of substrate materials including flexible polymers. In the final paper, we will discuss more experimental data along with printing conditions and the ink development process.

9116-15, Session 4

Multimaterial additive manufacturing of soft robot bodies with integrated arrays of sensors and actuators

Adam Cohen, Matt Saari, Collin Clay, Paul Krueger, Edmond Richer, Southern Methodist Univ. (United States)

Many emerging robotic platforms will require more than a handful of discrete, localized sensors to achieve the desired capabilities. Rather, they will need a distributed, multi-dimensional array of sensors as well as 3-D interconnects. Furthermore, in the case of soft robotics, it is also necessary to provide distributed actuators to control the large number of degrees of freedom. Fabricating a robotic body part comprising 100s or 1000s of distributed, interconnected sensors and actuators can be difficult with current approaches, which tend to produce assemblies that are costly, heavy, and bulky.

To address these challenges, we are developing a novel additive manufacturing technology that will enable the integrated fabrication of soft robotic bodies with distributed, built-in sensors and other elements. In essence, we aim to create a “robot printer” that automatically produces a pre-assembled, ready-to-use robotic limb, body, or other component. The focus is on capacitive sensors and electromagnetic actuators, though other modalities are envisioned. The research requires a number of advancements such as co-deposition of multiple materials in layered structures. Today’s additive manufacturing can only build structures from a single class of material (e.g., polymers or metals); overcoming this limitation will enable a wide range of active structures to be fabricated. Anticipated applications include advanced prosthetics, minimally-invasive surgical instruments, and wearable electronics.

This paper presents preliminary results for printing elastomers and conductive material simultaneously, and multi-physics simulations of the performance of capacitive sensors made using this technology. Approaches to optimizing sensor performance are also discussed.

9116-16, Session 4

Microassembly and packaging of carbon nanotube-based field emission devices for high temperature electronics applications

Rakesh Murthy, Jet Propulsion Lab. (United States)

Electronic components and circuitry capable of functioning at extreme temperatures are critical for robotiv space exploration. Missions related to Venus exploration for example, demand sensory, signal conditioning and communication modules to perform reliably above 400 deg C operating temperatures for extended periods of time. This paper describes hybrid microassembly and characterization of Carbon Nanotube based field emission devices designed to operate in such harsh environments. Two types of active devices- Diodes and Triodes consisting of multi-electrode stack and separated by thin dielectric layers are discussed. Emphasis is device design suitable for assembly based approach and on developing appropriate microassembly techniques. Both devices consist of a diverse set of materials including titanium, mica, molybdenum, etc. Finite element analysis based electrothermal stress analysis is used determine the structural feasibility of the hybrid assemblies, followed by the selection of appropriate bonding techniques and their verification using experiments. A multi-manipulator based microassembly platform capable of carrying out the high precision assembly and bonding operations is presented. Using machine vision based approach; post-assembly alignment verification has been implemented to characterize error along all six degrees of freedom (XYZ/Yaw Pitch Roll). A critical alignment parameter is the spacing achieved between electrodes since it influences the operating power. In our experiments we found the gaps to vary between 11?m-44?m in addition to the design values. Following assembly the diodes and triodes were tested inside a vacuum chamber to characterize their field emission characteristics, followed by vacuum encapsulation.

9116-20, Session 4

Force and joint angle measurements during activities of daily life

Joe Sanford, Nicoleta Bugnariu, Rita M. Patterson, The Univ. of Texas at Arlington (United States)

Research has expanded human-machine communication methods past direct programming and standard hand-held joystick control. Individual force sensors have been used as simple means of providing environmental information to a robot and research has shown that more advanced sensitive skins can be viable input devices. These touch sensitive surfaces allow for additional modes of interaction between machines in open, undefined environments. These interactions include object detection for navigation and safety but can also be used for recognition of a user’s command gestures by their machine partner. Key to successful implementation of these gestures is the understanding of varied strategies used for communication and interaction and the development of performance limits. Characterization data of dominant hand grip forces during activities that require interaction with common objects has been collected. Experimental methods describing data collection are included. Analysis of data from 10 male and female subjects is presented. The results of qualitative and quantitative analysis of these data show variability in interaction methods and hand configurations between users, variability in applied forces between users, and variability in interaction speeds, even when interacting with the same objects. These data will be used in future work to provide human metrology constraints and limits for use in simulation and design of new, physical human-robot interaction systems.

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9117-1, Session 1

Study on the digital hologram recording system with extra-large field of view *(Invited Paper)*

Jaisoon Kim, Myongji Univ. (Korea, Republic of); Jisoo Lee, Myongji Univ. (Korea, Republic of); Sanghee Lee, Myongji Univ. (Korea, Republic of); Jinoh Han, Myongji Univ. (Korea, Republic of); Jung-Young Son, Konyang Univ. (Korea, Republic of); Bong Ho Lee, Kyungae Moon, Jin-Woong Kim, Electronics and Telecommunications Research Institute (Korea, Republic of)

Recently, 3D imaging is one of the big research issues for wide application in engineering and commercial area. Many kind of limitations in real 3D using hologram can be overcome by inserting binocular disparity (stereoscopic) method. In addition, the recording process of hologram including complex rendering is get faster and easier with the aid of remarkable development in high speed computer and high resolution SLM (Spatial Light Modulator).1 Starting from the many contiguous vertical strip holograms for synthesizing a composite hologram from a horizontal sequence of incoherently recorded two-dimensional photographs2, various researches on the modification and improvement of multi dot recording method to maintain coherence, improve beam efficiency and fulfill colorization have been proceeded.3 Among them, one step with rendering and two steps recording for securing convenient viewing zone should not be over sighted. Lately, Zebra Imaging, Inc.4 has realized commercial version of full parallax 3D having large field of view. In this paper, designs of recording objective (Voxel control; VC) lens with extremely large viewing field satisfying required resolution, distortion, and tele-centricity are introduced. In addition, experimental results including the layout of prototype system are presented.

9117-2, Session 1

Experimental evaluation of reconstructed image quality in electronic holography using rectangular-shaped 1D SLM

Osamu Matoba, Kobe Univ. (Japan); Ayaka Ueno, Kobe Univ. (Japan); Kouichi Nitta, Kobe Univ. (Japan)

We have been developing an electronic holography system using one-dimensional (1D) spatial light modulator (SLM). In electronic holography using 1D SLM, only horizontal parallax is realized and vertical parallax is lost. However, it is expected that a large number of pixels can be realized in a 1D SLM by using MEMS technology. This leads to the reconstruction of high quality image and a large size image. There are some issues to be solved for the implementation of a 3D display system based on electronic holography using a 1D SLM. Image quality of reconstructed 3D image is one of important issues. So far, we have presented numerically a design method of rectangular-shaped pixel in 1D SLM by using criterion of contrast evaluation.

In this paper, we presented experimental results of evaluating reconstructed image quality using rectangular-shaped pixels. In the experiment, a part of 2D SLM where 4k2k pixels with a pixel size of 4.8 um is used to implement rectangular-shaped pixels as 1D SLM. When the reconstruction distance is 40 mm, the experimentally reconstructed images are compared with numerical results. We will discuss the reconstructed image quality when the reconstruction distance changes.

9117-3, Session 1

Holographic stereogram printing under the non-vibration environment

Bong Ho Lee, Electronics and Telecommunications Research Institute (Korea, Republic of)

Printing the holographic stereogram (HS) is vulnerable to the vibration when the holographic film is exposed to the continuous wave laser beam compared to the pulsed laser. The continuous wave laser is required to be longer exposed to the holographic film for forming the fringe pattern, hence the optical system is normally set up on the anti-vibration device such as optical table. This could be a latent defect in commercially available printers. This paper covers the design of holographic stereogram printing system which is built upon the non-vibration environment where the ambient vibration exists only.

In order to build a robust system under the common sources of vibration, we designed the optical system which can minimize the effects of ambient noise as well as reduce the optical vibrations. The main source of the noise comes from the stage that transfers the hologram plate hogel by hogel. In order to accelerate the step and scanning, we devised and applied an anti-vibration algorithm which can reduce the vibration significantly and the open frame architecture as well.

The holographic stereogram printing is conducted using the one-step full parallax stereograms which are generated by setting up the re-centered camera. The optical system features single signal beam converging module to minimize the optical components and tailored optical components. An open frame film stage is integrated into the HS system.

For the experiments, the horizontal and full parallax 1mmx1mm, 50x50 and 100x100 hogels are printed to verify the proposed HS printing system.

9117-4, Session 1

Accurate quantitative phase imaging through telecentric digital holographic microscopy

Manuel Martínez-Corral, Ana I. Doblas, Emilio Sánchez-Ortiga, Genaro Saavedra, Univ. de València (Spain); Jorge I. Garcia-Sucerquia, Univ. Nacional de Colombia Sede Medellín (Colombia)

The use of nontelecentric imaging systems in quantitative phase digital holographic microscopy introduces strong inaccuracies. We show that even negligible errors in the radius and center of curvature of the remaining quadratic phase factor introduce big errors in the numerical phase measurements. The errors depend on the position of the object in the field-of-view. However, when a telecentric imaging system is utilized for the recording of the holograms, the hybrid imaging method shows shift-invariant behav-ior, and therefore accurate quantitative phase imaging can be performed.

9117-5, Session 1

Measurement of depth representation using integral imaging for quality evaluation of computer-generated hologram

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Holographic display has attracted growing attention as an ultimate 3D display technology. However, until now, most researches have focused on

novel display systems, reduction of computational complexity and/or speed-up of processing time for computer-generated hologram (CGH), but few on measurement and evaluation of holographic image quality itself. Therefore, we propose an efficient quality measurement scheme for holographic images, especially focusing on depth representation among various properties such as brightness, resolution, degree of noise and so on.

We extract the depth information of holographic images from the depth-priority integral imaging. The holographic image through lens array is captured by camera focusing on focal plane of lens array. From a single capture, depth information can be obtained as a form of disparity with spatio-angular distribution. Though there are more direct methods for acquiring depth information such as using depth camera based on time-of-flight (TOF) or structured light, those methods are not suitable for holographic image reconstructed by superposition of wave, which cannot reflect the light.

In experiment, CGH for an object on several discrete planes is reconstructed by spatial-light modulator (SLM). From capturing elemental images of the holographic image, we first extracted a set of focused images and then exploit statistical spatial properties of each focused image to determine depth of planes at which the holographic image exists. As a result, we verified that calculated depth of the object (holographic image) from integral imaging is well matched to the directly measured distance. This result confirms that our proposed method is effective to measure the depth representation of holographic image for quality evaluation of CGH.

9117-6, Session 1

Generation of three-dimensional color images by a horizontally scanning holographic display *(Invited Paper)*

Yasuhiro Takaki, Tokyo Univ. of Agriculture and Technology (Japan)

Since holographic displays can produce sharp three-dimensional (3D) images without blur, viewers can focus on 3D images as they do on real objects. Thus, holographic displays are free from vergence-accommodation conflict. In the conventional electronic implementation of holography using a spatial light modulator (SLM), screen size and viewing zone angle are limited; horizontally scanning holography was proposed to enlarge both. The system consists of an anamorphic imaging system, a horizontal scanner, and an MEMS SLM, which generates images at a high frame rate. These images are compressed horizontally and enlarged vertically by the anamorphic imaging system. The vertically enlarged image, which is an elementary hologram, is scanned horizontally by the horizontal scanner. The pixel pitch of the SLM is reduced horizontally to increase the horizontal viewing zone angle. The vertically enlarged image is scanned horizontally to increase the screen size. Recently, the generation of 3D color images was achieved by introducing RGB lasers into the display system. Because the MEMS SLM can generate images with a sufficiently high frame rate, there is a substantial overlap between elementary holograms so that several sets of elementary holograms can be generated by a single horizontal scan. A different elementary hologram set is displayed with a different color. Color images with a screen size of 6.2 in. and a viewing zone angle of 11° were produced using a digital micromirror device with a frame rate of 22.727 kHz as the MEMS SLM.

9117-7, Session 1

Fluctuations in the intensity read out of CCD arrays in digital holographic setups: an experimental investigation

Yang Wu, Damien P. Kelly, Stefan Sinzinger, Technische Univ. Ilmenau (Germany); Adrian Stern, Ben-Gurion Univ. of the Negev (Israel)

In modern optical systems discrete digital devices for measuring intensity distributions play an indispensible role. The intensity incident on the CCD or CMOS array is averaged over the spatial extent of each pixel for a given exposure time. Fluctuations in the power of a laser, vibrations on an optical table, and electronic noise from the digital sensor all contribute to some degree to a base-line noise level for a particular optical system. Hence we expect that the intensity value measured by each pixel will fluctuate over time. In this paper we investigate the effects of noise of CCD arrays over time using a speckle field for a range of different CCD parameters such as exposure time, gain factor, and light power. We then examine how this baseline noise level changes when the incident speckle field is mixed with a plane reference wave forming to form a hologram at the CCD plane. We comment on our experimental results and how they apply to general optical systems that measure the phase distribution for a complex field.

9117-13, Session 1

Portable low-coherence interferometry for quantitatively imaging fast dynamics with extended field of view *(Invited Paper)*

Natan T. Shaked, Tel Aviv Univ. (Israel)

We present our recent advance in the development of compact, highly portable and inexpensive wide-field interferometric modules. By a smart design of the interferometric system, including the usage of low-coherence illumination sources and common-path off-axis geometry of the interferometers, spatial and temporal noise levels of the resulting quantitative thickness profile can be sub-nanometric, while processing the phase profile (including phase unwrapping) in real time. In addition, due to novel experimentally-implemented multiplexing methods, we can capture low-coherence off-axis interferograms with significantly extended field of view and in faster acquisition rates. Using these techniques, we quantitatively imaged rapid dynamics of live biological cells including sperm cells and unicellular microorganisms. Then, we demonstrate dynamic profiling during lithography processes of microscopic elements, with thicknesses that may vary from several nanometers to hundreds of microns. Finally, we present how rapid interferometry can be helpful for tissue engineering applications, to characterize rapid drug release from skin equivalents in vitro.

9117-8, Session 2

Speckle suppression in computational hologram generated using ray-sampling plane *(Invited Paper)*

Masahiro Yamaguchi, Takeru Utsugi, Tokyo Institute of Technology (Japan)

The advantage of holography in 3D display application is the capability of reproducing all the depth cues for human vision, especially for high-resolution image display of deep 3D scene. On the other hand, an important issue in holographic display is the appearance of speckle noise. If we reduce the coherence of the illumination light to reduce speckle, the image resolution is degraded especially in the case of deep 3D scene. Then the question that should be addressed is whether the resolution of reconstructed image is affected by applying speckle suppression or not. In this paper, the resolution of the 3D image reproduced by a computational holography is discussed when speckle suppression technique is applied. We also introduce a new technique for reducing speckle noise in a computer generated hologram (CGH) calculated using a ray-sampling (RS) plane [1]. The method for CGH calculation using RS plane enables the application of conventional 3D rendering techniques, as well as the high-resolution display of deep 3D scene. To reduce speckle noise, the sparse object points are incoherently superposed as in the same manner as the method proposed by Takaki and Yokouchi [2]. This method is applied to ray-based CGH calculation, by selecting light-rays that reconstruct sparse object points and adding optimized phase to each light-ray [3]. The sampling rate of sparse object points is optimized by the speckle size that is determined by the pupil size of an observer's eye. As a result, it is shown that the resolution of the reconstructed image is better than the resolution of the human vision that is restricted by the diffraction limit of observer's eye pupil. Namely, high-resolution display of deep 3D image is still possible even if speckle suppression is applied.

[1] K. Wakunami and M. Yamaguchi, "Calculation for computer generated hologram using ray-sampling plane," Opt. Express, 19 (10), 9086–9101 (2011).

[2] Y. Takaki and M. Yokouchi, "Speckle-free and grayscale hologram reconstruction using time-multiplexing technique," Opt. Express, 19 (8), 7567–7579 (2011).

[3] M. Yamaguchi, H. Hoshino, T. Honda, and N. Ohyama, "Phase-added stereogram: calculation of hologram using computer graphics technique," Proc. SPIE, 1914, 25–33 (1993).

9117-9, Session 2

Acceleration of color computer-generated hologram from three-dimensional scenes with texture and depth information *(Invited Paper)*

Tomoyoshi Shimobaba, Takashi Kakue, Tomoyoshi Ito, Chiba Univ. (Japan)

We propose acceleration of color computer-generated holograms (CGHs) generated from three-dimensional (3D) scenes that are expressed as texture and depth information, which can be regarded as two-dimensional (2D) stacking images along depth direction. This information is obtained by 3D graphics libraries or depth cameras. The generation of such CGHs requires multiple diffraction calculations from the 2D stacking images. If we use convolution-based diffraction such as the angular spectrum method, the diffraction calculation take long calculation time and requires the large memory usage because the convolution diffraction calculation requires the expanded area of the 2D stacking images to eliminate the wraparound noise.

In this paper, we propose the acceleration of the diffraction calculation using "Band-limited double-step Fresnel diffraction" that does not require the expanded area. In addition, for color CGHs from color 3D scenes, we propose color CGH acceleration using color space conversion. In general, color CGH generation is done on RGB color space; however, we need to repeat the same calculation for each color component, so that the calculation cost of the color CGH generation increases three times than monochrome CGH generation. We can reduce the calculation cost by using YCbCr color space because the 2D stacking images on YCbCr color space can be down-sampled without the impairing of the color quality.

9117-10, Session 2

Digital speckle reduction: a comparison between methods

Adrian Stern, Vladimir Farber, Ben-Gurion Univ. of the Negev (Israel)

Digital holography, as any coherent imaging modalities, is subject to speckle noise that may significantly degrade the image quality. Several optical and digital speckle reduction techniques were developed. In this paper we compare the performance of some common digital speckle denoising techniques.

9117-11, Session 2

Multi-parameter motion-picture recording with wide space-bandwidth by parallel phase-shifting digital holography *(Invited Paper)*

Tatsuki Tahara, Kansai Univ. (Japan); Peng Xia, Yasuhiro Awatsuji, Kenzo Nishio, Shogo Ura, Kyoto Institute of Technology (Japan); Toshihiro Kubota, Kubota Holography Lab. Corp. (Japan); Osamu Matoba, Kobe Univ. (Japan)

High-speed color 3D motion-picture recording with wide space-bandwidth was experimentally demonstrated by using multi-wavelength parallel phase-shifting digital holography. Parallel phase-shifting digital holography is a technique for obtaining amplitude and phase distributions of an object wave simultaneously from a single hologram, based on space-division multiplexing of multiple phase-shifted holograms. The 0th-order diffraction wave and conjugate image are removed from a recorded single hologram by applying parallel phase-shifting interferometry. Parallel phase-shifting has wider space bandwidth available for recording an object wave in comparison to an off-axis configuration applying the Fourier transform method. Any experimental demonstration of color imaging has not been conducted in parallel phase-shifting due to the requirement of developing a special image sensor that has both arrays of micro color filters and micro polarizers. This time, the combination of parallel phase-shifting with angular multiplexing is proposed to capture multi-color information simultaneously. Complex amplitude distributions of multiple wavelengths are simultaneously recorded with a single-shot exposure of a single monochromatic image sensor by adopting angular multiplexing to parallel phase-shifting. Multi-wavelength information is separated in the spatial frequency domain by applying angular-multiplexed recording and no color filter is required. Color 3D motion-picture recording of objects that move at the speed of more than 20 km/h was achieved at 20,000 frames per second. This result is the first experimental demonstration of multi-wavelength parallel phase-shifting digital holography.

9117-12, Session 3

Liquid crystal lens array for 3D endoscope application *(Invited Paper)*

Amir Hassan Firoozi, Tai-Hsiang Jen, National Chiao Tung Univ. (Taiwan); Yi-Pai Huang, National Chiao Tung Univ. (Taiwan); Han-Ping D. Shieh, National Chiao Tung Univ. (Taiwan)

A tunable liquid crystal lens arrays with curved circular electrodes is developed. The ITO is deposited on the outer surface of the plano-convex of an AZ series photo-resist. All lenses are arranged in a hexagonal with a small inactive region. The micro lens array consists of two sub lenses, one is the liquid crystal layer which is electrically tunable and the other is the NOA81 (Norland Optical Adhesive) as a fixed focal length. We are taking the advantage of using curved circular electrodes in order to have a much suitable electric field distribution without using transparent electrodes as a lens itself. We proposed a LC lens with cell gap of 30μm. The electric field gradually decreases from center of electrode to the edge of electrode which can create better uniformity of distributed electric field, especially for a lens with a very small aperture size. Furthermore, varying voltage causes a fast varying electric field. Simple fabrication, miniaturizing the lens size and its low voltage property, 3D-2D switchable image acquisition, a proper focal length for endoscope are the features of this kind of lens array.

9117-14, Session 3

High dynamic depth range for 3D image capturing system

Yi-Pai Huang, National Chiao Tung Univ. (Taiwan); Po-Yuan Hsieh, National Chiao Tung Univ. (Taiwan); Yong-Ren Su, Han-Ping D. Shieh, National Chiao Tung Univ. (Taiwan)

To detect the 3D depth information of objects in a deep scene is not so easy due to the limited depth of field (DoF) of cameras. In this paper, we proposed a 3D depth map capturing system with high dynamic depth range (HDDR). Unlike conventional extending depth of field (EDoF) method, the HDDR method doesn't need applying optical units, and will not deteriorate the image quality. By imitating an active tunable m?n lens array focusing on a sequential of imaging planes, each object in this scene would be clearly captured by at least three elemental lenses. We estimated the elemental depth maps by using the method depth from disparity individually, and then fused them into one all-in-focus depth map. Comparing with the conventional 3D cameras, the working range of HDDR system with 3x3 camera array can be extend from 90cm to 165cm.

9117-15, Session 3

Scattering super lens: subwavelength light focusing and imaging via holographic control in complex media *(Invited Paper)*

YongKeun Park, KAIST (Korea, Republic of)

The resolution limit using visible light is a limiting factor in many fields of research. This is especially undesirable for bio- and nano-photonics where imaging and focusing at the sub-diffraction limited regime is critical. Due to these limitations, various novel schemes have been developed allowing sub-diffraction limited imaging using visible light. However, fluorescent nanoscopic methods such as Stochastic Optical Reconstruction Microscopy (STORM), PhotoActivated Localization Microscopy (PALM), or structured illumination rely on numerical post-processing to achieve super resolution and cannot excite or perturb sub-diffraction limited spots physically. Other methods such as Stimulated Emission Depletion (STED) microscopy emits fluorescence in sub-diffraction limited volumes but works only on fluorophores where another beam can be used to de-excite the fluorescence.

In this work, we demonstrate that we can use multiple scattering to obtain a sub-diffraction limited focus at an arbitrary position. Due to the random structure of the highly scattering media, there are no restrictions on the physical position of the focus giving the system a high degree of freedom. Through this demonstration we propose that multiple scattering in biological tissue, which had been assumed to be unfavorable for imaging or light treatment, can on the contrary be used to steer and focus sub-diffraction limited light spots with arbitrary polarization or wavelength within its inhomogeneous structure. The wavelength of light is also shown to be independent on the size of the obtained focus which gives this method a broad range of spectral applicability as resonance is not its working mechanism.

9117-16, Session 3

From the plenoptic camera to the flat integral-imaging display *(Invited Paper)*

Manuel Martínez-Corral, Adrián Dorado, Hector Navarro, Anabel Llavador, Genaro Saavedra, Univ. de València (Spain); Bahram Javidi, Univ. of Connecticut (United States)

Plenoptic cameras have become popular devices along the past few years. Based on the old concept of integral photography, reported by Lippmann at the beginning of the 19th century, these cameras capture a sampled version of the map of rays emitted by a 3D scene. Plenoptic cameras have been proposed for the calculation of depth maps and also sets of views of the 3D scene. They can also be used as method, alternative to the classical Hartmann-Shack one, for measuring wavefront distortions. In this contribution we report a new algorithm for transforming the plenoptic frame into a picture ready to be projected onto an integral-imaging monitor, and therefore display 3D images with full parallax.

9117-17, Session 4

Principle and recent developments on depth-fused 3D (DFD) display *(Invited Paper)*

Hirotsugu Yamamoto, Atsuhiro Tsunakawa, Univ. of Tokushima (Japan); Junnosuke Kawakami, Univ. of Tokushima (Japan); Shiro Suyama, Univ. of Tokushima (Japan)

This invited paper deals with depth-fused 3D (DFD) display. DFD display needs only two conventional 2D displays in order to provide 3D depth for an observer without glasses. Two overlapped images in front and rear planes can be perceived as a single depth-fused image. The perceived depth of this fused image continuously changes as the luminance ratio of the two images is changed. Moreover, DFD display has small but smooth movement parallax, which enables natural 3D perception.

We explain principle for DFD display based on a stereoscopic viewing model. Viewed images at both eye positions are simulated based on geometrical optics. In order to detect intensity changes, we have utilized Laplacian operation on a Gaussian blurred image. Stereoscopic depths are calculated by matching the Laplacian operated images. By adjusting standard deviation of the Gaussian blur function, theoretical curves agreed with the experimental results.

Furthermore, we show recent developments on DFD display. One of them is a deep DFD display technique to overcome the limitation to fuse the overlapped two images. As the distance between front and rear planes is increased over 5 min. of arc, perceived depth is separated near front plane, at mid-position and near rear plane. We found a solution to enlarge the depth limitation for the fusion. By using low-pass filtered front and rear images, almost linear dependence of perceived depth has been achieved. Then, we show our recently developed DFD display by use of full-color LED panels, which provide 50-cm depth at 5-m viewing distance.

9117-18, Session 4

Novel measurement method of multiview 3D display for determining an optimum viewing distance (OVD)

Ki Hyuk Yoon, Korea Institute of Science and Technology (Korea, Republic of) and Univ. of Seoul (Korea, Republic of); Hyunwoo Kim, Seon Kyu Yoon, Korea Institute of Science and Technology (Korea, Republic of) and Korea Univ. (Korea, Republic of); Sung Kyu Kim, Korea Institute of Science and Technology (Korea, Republic of)

The optical property of multi-view 3D display system using parallax barrier is generally slightly different from designed values. The representative values among the designed values of multi-view 3D display system are the optimum viewing distance (OVD) and the view-point distance (VPD) in OVD. In order to estimate an image quality of multi-view 3D display, OVD is usually measured and the optical characteristics such as crosstalk and luminance uniformity are evaluated in measured OVD. Various evaluation methods of multi-view 3D display have been presented. But, an exact measurement method of OVD and decision method of position error of view-point images formed from entire 3D display area are not presented until now. Therefore, the first purpose of this study is to suggest a new method for determining an exact or effective OVD and VPD basing on measurements of multi-view 3D display. The other is to suggest method for determining position error range of view-point images formed different area of multi-view 3D display. Using the new decision method of OVD and VPD in this paper, we think that more objective evaluation for optical property of multi-view 3D display can be realized.

9117-19, Session 5

In memoriam: Fumio Okano, innovator of 3D displays *(Invited Paper)*

Jun Arai, NHK Japan Broadcasting Corp. (Japan)

Dr. Fumio Okano, a well-known pioneer and innovator in 3D displays, passed away on 26 November 2013 in Kanagawa, Japan, at age 61.

Okano contributed more than 40 papers to SPIE journals and proceedings since 1998. He served eight years as chair of the annual SPIE conference on Three-Dimensional Imaging, Visualization, and Display, and another four years as co-chair.

Okano received his B.S., M.S., and Ph.D. degrees in electrical engineering from Tohoku University, Sendai, Japan. He joined Japan Broadcasting Corporation (NHK) in Tokyo in 1978. Since 1981, he had researched high-definition television (HDTV) cameras, HDTV systems, 3D televisions, and ultrahigh-definition television systems at NHK Science and Technology Research Laboratories.

In 2011, he moved to NHK Engineering System, Inc., where he worked as managing director and executive research engineer. Dr. Okano was a fellow at the Institute of Electrical and Electronics Engineers (IEEE) and a member of the Institute of Image Information and Television Engineers of Japan, Optical Society (OSA), and SPIE.

His publications are frequently cited by researchers. Okano's leadership in this field will be greatly missed and he shall be remembered for his enduring innovations and contributions in the field of 3D displays.

9117-21, Session 5

3D reconstruction method based on time-division multiplexing using multiple depth cameras

Ji-Hoon Kang, Dong-Su Lee, Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of); Kwang-Hoon Lee, Korea Photonics Technology Institute (Korea, Republic of)

A conventional method for 3D scene Reconstruction was performed with laser scanner or multiple color cameras. However, a laser scanner is expensive and slow and the method based on multiple color cameras is inaccurate. The active depth camera can be an alternative method for 3D scene reconstruction because of its cheap and accurate depth measurement scheme for 3D reconstruction. Therefore, in this research, active depth camera is used for cheap and efficient 3D scene reconstruction.

Since the depth camera acquires the depth information from a single viewpoint, it's inadequate for 3D reconstruction when using single depth camera. In order to solve this problem, multiple depth cameras are used. For 3D scene reconstruction, the depth information is acquired from a different viewpoint with multiple depth cameras. However, the use of multiple depth camera can lead to problems.

The depth camera emits infrared rays to acquire the depth information. When using multiple depth cameras, it's difficult to acquire accurate depth information because of interference among depth cameras. To solve this problem, in this research, Time-division multiplexing is used. Simply, acquire the depth information from different cameras one by one at different time.

After acquiring the depth images, extract features using Fast Point Feature Histogram (FPFH) descriptor. Then, perform 3D registration using algorithm such as Sample Consensus Initial Alignment (SAC-IA).

We expect the proposed method reconstructs 3D scene with high accuracy and high speed. Also, the method can be applied to various fields such as garment industry or 3D printer industry.

9117-22, Session 5

Noninterferometric tomographic reconstruction of 3D static and dynamic phase and amplitude objects *(Invited Paper)*

Sarvenaz Memarzadeh, Univ. of Dayton (United States); Georges T. Nehmetallah, Catholic Univ. of America (United States); Partha P. Banerjee, Univ. of Dayton (United States)

Non-interferometric intensity based methods of phase retrieval such as the transport of intensity equation (TIE) employs a simple experimental technique for amplitude and phase reconstruction of a static object by capturing several diffraction patterns at different observation planes. The purpose of this work is to numerically and experimentally extend this technique to moving phase and amplitude objects. The simulation part is done based on solving the TIE equation using the Fast Fourier Transform (FFT) method, and the amplitude and the calculated phase in the detection plane is numerically back-propagated to the object plane using the paraxial transfer function. A modified form of TIE, which subtracts higher order derivatives to improve accuracy of the finite difference approximation, is also used. Furthermore, we illustrate how a static 3D phase and/or amplitude object can also be reconstructed tomographically by illuminating it at multiple angles. For illustration purposes, the object is mounted on a rotating stage and multiple diffraction patterns are captured for different angles and at different observation planes. The reconstructed optical fields are tomographically recomposed to yield the final 3D shape using a simple multiplicative technique. The tomographic technique can be generalized for the case of 3D moving objects.

9117-52, Session 5

High-precision microscopic phase imaging without phase unwrapping for cellular function evaluation *(Invited Paper)*

Eriko Watanabe, The Univ. of Electro-Communications (Japan)

There has been considerable demand for the cell inspection without invasion, destruction, and in regenerative medicine and pathological examination. For realizing this demand, researchers from various fields of medicine have been attracted to quantitative phase measurement techniques. Studies on the analysis of cell information using phase amount have been carried out using FF-OCM (full-field optical coherence microscopy), digital holographic microscopy, phase shift microscopy, etc. However, these conventional systems need a phase unwrapping process when the phase retardation is larger than 2ϖ radians. Phase unwrapping may fail when the phase distribution contains sharp rises and declines, has high spatial resolution, and is complex over several.

In this talk, we show our high-dynamic-range two-dimensional phase measurement system without phase unwrapping processing and discuss recent work on its applications in the biomedical field. The optical setup of this system is based on the Mach–Zehnder interferometer and uses the phase-locking technique. We demonstrate how this technique performs quality control of cultivated cells as well as cancer identification. Thus, the system is applicable for evaluating the limitations of the "passages culture" of biological cells. The optical path length decreases significantly from passage 3 onwards. This result is in excellent agreement with those of the bio analysis method. In addition, the experimental results indicate that cancerous cells could be distinguished from normal cells using our developed system.

9117-20, Session Posters-Tuesday

Digital holographic visualization of thermally induced optical parameter changes in micro-obejcts

Janak Rathod, Jignesh Pandya, Nimit R. Patel, Swapnil Mahajan, Vismay Trivedi, Vani Chhaniwal, The Maharaja Sayajirao Univ. of Baroda (India); Bahram Javidi, Univ. of Connecticut (United States); Arun Anand, The Maharaja Sayajirao Univ. of Baroda (India)

One of the state of the art technique used for three dimensional imaging of micro-objects is digital holographic microscopy. This single shot technique directly yields the complex amplitude of the magnified object wavefront, which could be used to retrieve the object phase information leading to mapping of the optical thickness. From the retrieved phase information obtained from a series of holograms, information about the spatio-temporal evolution of optical thickness can be attained. For dielectric mediums, any temperature changes lead to change in optical parameters. Here we describe the use of digital holography in imaging optical path length variations to visualize the changes in optical parameters both spatially and temporally.

9117-23, Session Posters-Tuesday

Photorealistic image synthesis and camera validation from 2D images

Juan C. Santos Ferrer, David M. González Chévere, Vidya B. Manian, Univ. de Puerto Rico Mayagüez (United States)

Spectral sensing in the visible and infrared regions is usually done using digital and infrared imaging cameras. Simulating the camera parameters and hence reconstructing the captured scenes, and validating them with real world scenes will provide insight into camera settings and parameters that are appropriate for changing complex real world situations. This has several applications in satellite remote sensing, defense, sensing and security and biomedical imaging applications. We reconstruct 3D scenes from 2D images taken from indoor and outdoor scenes with different cameras settings such as IR color and black and white, and explore different properties in the reconstructions of the scenes including light, color, texture, shapes and different views. Matlab and Unity 3D pro tools are used to explore and get different properties from the 2D images and for reconstructing the 3D scenes, respectively. In a photorealistic 3D reconstruction the reconstructed scene should accurately reproduce the original image, presevering color, texture and pixel resolution. We can model the real word texture using strategies such as triangulated polygons, homographies, and by the extraction of partial textures from visible surfaces to achieve the highest possible resolution. Methods like edges detection, line parallelism, line orthogonally, face parallelism and face orthogonally will be used to recover the 3D shapes of the objects from images sparsely distributed across the range of views. The quality of the synthetic scenes will be evaluated taking into consideration the quality of the original 2D image, the functionality of the game software module developed for simulating a particular scene and the variability of the parameter settings for simulating a particular target or background.

9117-36, Session Posters-Tuesday

Spatial distortion elimination in integral Fourier holography with intermediate projection views generation method

Chen Yang, Xidian Univ. (China) and Univ. of Connecticut (United States); Xiaorui Wang, Xidian Univ. (China); Bahram Javidi, Univ. of Connecticut (United States)

In integral holography, the reconstructed 3D image quality is affected by positional errors in micro-lens array. We analyzed the spatial distortion effects in reconstructed 3D integral Fourier holographic image which are caused by misarrangements of elemental lens in micro-lens array. Then, an intermediate projection views generation method is proposed to eliminate the spatial distortion effects in the reconstruction. This method provides a solution to adjust the lens-array manufactured errors in realistic integral holographic imaging.

9117-37, Session Posters-Tuesday

Bayesian estimation of depth information in three-dimensional integral imaging

Xiao Xiao, Bahram Javidi, Dipak K. Dey, Univ. of Connecticut (United States)

In this paper, we propose a Bayesian framework to infer depths of object surfaces in a 3D integral imaging system. In a 3D integral imaging system, the depth of Lambertian surfaces can be estimated from the statistics of the spectral radiation pattern. However, the estimated depth may contain errors due to system uncertainties. To better infer the depth information, we utilize a Bayesian framework and a Markov Random Field (MRF) model with the knowledge of the statistical information of object intensities and the assumption that object surfaces are smooth. In the proposed method, we combine a Bayesian framework and the characteristics of 3D integral imaging systems to infer the depths. Simulated and experimental results illustrate the performance of the proposed method.

9117-38, Session Posters-Tuesday

Three-dimensional object recognition via integral imaging and scale invariant feature transform

Faliu Yi, Inkyu Moon, Chosun Univ. (Korea, Republic of)

We propose a three-dimensional (3D) object recognition approach via computational integral imaging and scale invariant feature (SIFT) that can be invariance to object changes in illumination, scale, rotation and affine. Usually, the matching between features extracted in reference object and that in computationally reconstructed image should be done for 3D object recognition. However, this process needs to alternately illustrate all of the depth images first which will affect the recognition efficiency. Considering that there are a set of elemental images with different viewpoint in integral imaging, we first recognize the object in 2D image by using five elemental images and then choose one elemental image with the most matching points from the five images. This selected image will include more information related to the reference object. Finally, we can use this selected elemental image and its neighboring elemental images which should also contain much reference object information to calculate the disparity with SIFT algorithm. Consequently, the depth of the 3D object can be achieved with stereo camera theory and the recognized 3D object can be reconstructed in computational integral imaging. This method sufficiently utilizes the different information provided by elemental images and the robust feature extraction SIFT algorithm to recognize 3D objects.

9117-39, Session Posters-Tuesday

Optimized NURBS skinning surface using a gravitational search algorithm

Siti Mariyam H. Shamsuddin, Univ. Teknologi Malaysia (Malaysia)

Usually, a skinning method involves skinning interpolation and skinning approximation. Skinning interpolation constructs a surface perfectly, but improper selection of parameterization methods could cause bumps, wiggles, or uneven surfaces on the generated surface. Conversely, a skinning approximation approximates the data points for surface reconstruction.

In this scenario, the error between generated surfaces and data points must be minimized to increase the accuracy. In this paper, we propose a new skinning method called Non-Uniform Rational B-Spline (NURBS) and optimize the reconstructed surfaces using a Gravitational Search Algorithm (GSA). This method is implemented to solve the error minimization problem to obtain a smoother and fairer surface. Findings from the experiments are then compared with the interpolation and a conventional approximation skinning method. The results show that the optimized skinning surfaces using GSA yield a smaller error with fewer control points and feasible surfaces while maintaining the shape of the surfaces.

9117-40, Session Posters-Tuesday

Volumetric display containing multiple two-dimensional color motion pictures

Ryuji Hirayama, Chiba Univ. (Japan); Atsushi Shiraki, Kisarazu National College of Technology (Japan); Hirotaka Nakayama, Takashi Kakue, Tomoyoshi Shimobaba, Tomoyoshi Ito, Chiba Univ. (Japan)

We have developed an algorithm which can record multiple two-dimensional gradated projection patterns in a single three-dimensional object. Each recorded pattern has the individual projected direction and can only be seen from the direction. When a single pattern is observed, information from the other patterns can be treated as background noise. The proposed algorithm has two important features: the number of recorded patterns is theoretically infinite and no meaningful pattern can be seen outside of the projected directions.

In this paper, we expanded the algorithm to record multiple two-dimensional projection patterns in full color. There are two ways of color mixing: Additive ones and Subtractive ones. Additive mixing based on RGB colors is used to mix light and Subtractive mixing based on CMY colors is used to mix inks. We established two coloring methods based on the Additive mixing and Subtractive mixing. We performed numerical simulations of coloring methods, and confirmed the effectiveness.

We also fabricated two types of volumetric display and applied the proposed algorithm to them. One is a cubic display constructed by light-emitting diodes (LEDs) in 8x8x8 array. Light patterns of LEDs are controlled by a microcomputer board. Another one is made of 7x7 array of threads. Each thread is illuminated by a projector connected with PC. As a result of the implementation, we succeeded in recording multiple two-dimensional color motion pictures in the volumetric displays. This algorithm can be applied to digital signage, media art and so forth.

9117-42, Session Posters-Tuesday

Extended viewing-angle holographic display with optical fiber arrays backlight

Hyun-Eui Kim, Minsik Park, Kyungae Moon, Jin-Woong Kim, Electronics and Telecommunications Research Institute (Korea, Republic of)

The restrictive space-bandwidth product of the spatial light modulator for holographic display is an obstacle to entering the three-dimensional display market. Holographic stereogram technique is a typical way to increase the space-bandwidth product. Even though holographic stereogram technique provides a wider viewing-angle, this method requires multiple spatial light modulators, which makes the overall system complicated and expensive. We present wide-viewing angle holographic three-dimensional display using single mode optical fiber arrays backlight and a pupil-tracking technique. Beams generated in the multiple optical fibers arranged in circular configuration incident on a single spatial light modulator. Next to the spatial light modulator, 6inch lens adjust the scale of magnification of the reconstructed 3D image. According to the result, continuous wide viewing windows are formed without any overlaps, and the size of reconstructed 3D image increased up to 6inch. The spatial light modulator provides the proper perspectives of the 3D image to the display observer by acquired pupil positions of display observer using pupil-tracking module. Fiber-based approach provides a simple and robust alignment, high miniaturization.

9117-43, Session Posters-Tuesday

High-resolution TFT-LCD for spatial light modulator from ETRI

Chi-Sun Hwang, Yong Hae Kim, Gi Heon Kim, Chunwon Byun, Himchan Oh, Hye Yong Chu, Electronics and Telecommunications Research Institute (Korea, Republic of)

SLM with very fine pixel pitch is needed for the holographic display system. Among various kinds of SLMs, commercially available high resolution LCoS has been widely used as a spatial light modulator. But the size of commercially available LCoS SLM is limited because the manufacturing technology of LCoS is based on the semiconductor process developed on small size Si wafer.

Recently very high resolution flat panel display panel (~500ppi) was developed as a “retina display”. Until now, the pixel pitch of flat panel display is several times larger than the pixel pitch of LCoS. But considering the possibility of shrink down the pixel pitch with advanced lithographic tools, the application of flat panel display will make it possible to build a SLM with high spatial bandwidth product.

High resolution TFT-LCD panel on glass substrate is developed for the SLM of holographic display. Oxide semiconductor TFT with BCE structure and LC with phase modulation mode are integrated with pixel pitch of 20um. The TFT-LCD panel is reflective type with 4-metal structure with organic planarization layers.

The technical challenge for high resolution large area SLM will be discussed.

9117-44, Session Posters-Tuesday

Optical fiber trap and digital holographic microscope integrated setup

Samira Ebrahimi, Ali-Reza Moradi, Univ. of Zanjan (Iran, Islamic Republic of); Arun Anand, The Maharaja Sayajirao Univ. of Baroda (India); Bahram Javidi, Univ. of Connecticut (United States)

The combination of optical trap and digital holography is an elegant method for three-dimensional imaging of biological structures, while they are immobilized and manipulated with the trapping beam. In this paper, we integrated an optical fiber trapping setup with a compact common-path digital holographic microscope. The trapping beam path is separated from the holography beam path using a tapered multimode optical fiber for trapping. The common-path digital holographic microscopy setup is mounted on a conventional microscope. The trap is calibrated using a high-speed camera and trap stiffness is determined through power spectrum method. Some validation experiments are presented and the quantitative phase contrast images of the trapped samples are obtained by post-processing the recorded digital holograms.

9117-45, Session Posters-Tuesday

Nondestructive analysis of advanced materials nonlinear behavior using digital projection moiré

Yousef Pourvais, Pegah Asgari, Ali-Reza Moradi, Omid Rahmani, Univ. of Zanjan (Iran, Islamic Republic of)

This paper presents a new experimental procedure based on the digital projection moiré (DPM) for analyzing the non-linear behavior of sandwich beam with compliant foam core. This kind of core is very flexible relative to the face sheets and its behavior is associated with localized effects in the

form of localized displacements and stresses which influence the overall behavior of sandwich beam. In this study the three point bending results of sandwich beam have compared well with FEA results obtained using the ABAQUS finite element code. Also the theoretical predictions based on the high-order sandwich panel theory (HSAPT) were in good agreement with the experimental as well as FEM results. It is shown that the proposed procedure produces results with very high accuracy, and it is suggested that the present method, which is based on digital projection moiré, can be used as a simple, advantageous and user friendly whole-field testing technique for many applications in evaluation of composite materials and sandwich structures.

9117-46, Session Posters-Tuesday

Controlled phagocytosis by multiple optical traps

Adel Nasehi, Fatemeh Rezaei, Univ. of Zanjan (Iran, Islamic Republic of); Ali-Reza Moradi, Univ. of Zanjan (Iran, Islamic Republic of) and Institute for Advanced Studies in Basic Sciences (Iran, Islamic Republic of); elnaz nasehi, Univ of Zanjan (Iran, Islamic Republic of)

In this paper phagocytosis phenomenon is studied using multiple and multi-force optical traps. Phagocytosis is the process of engulfing a solid ?particle by a phagocyte or a protist to from an internal phagosome.?? The process is the central mechanism in the immune system, and is undertaken if certain mechano-chemical conditions are met. The trap cites and strengths' are controlled by implementing appropriate diffractive optical elements (DOEs) on a liquid crystal spatial light modulator. The manipulation of the a?phagocyte cell and the target are then controlled by trapping their peripherals. The reaction mechanism between the trapped phagocyte cell and the? prey are then studied in terms of the time of the process for various sizes of the targets and the distance between them and the cell when the process starts. The measurements were accomplished by post-processing of the recorded images during the process.

9117-47, Session Posters-Tuesday

Multispectral photon counting integral imaging system for color visualization of photon limited 3D scenes

Inkyu Moon, Chosun Univ. (Korea, Republic of)

In this paper, we overview a colorful photon-counting integral imaging system using Bayer elemental images for 3D visualization of photon limited scenes. The color image sensor with a format of Bayer color filter array, i.e., a red, a green, or a blue filter in a repeating pattern, captures elemental image set of a 3D scene. It is assumed that the observed photon count in each channel (red, green or blue) follows Poisson statistics. The reconstruction of 3D scene with a format of Bayer is obtained by applying computational geometrical ray back propagation algorithm and parametric maximum likelihood estimator to the photon-limited Bayer elemental images. Finally, several standard demosaicing algorithms are applied in order to convert the 3D reconstruction with a Bayer format into a RGB per pixel format. We measure the interpolation accuracy as well as the speed of the method. Experimental results demonstrate that the better performance can be achieved by a gradient-corrected version of the linear interpolation in terms of PSNR metrics.

9117-48, Session Posters-Tuesday

Curve-based representation and analysis of 3D facial expressions

Manar D. Samad, Khan M. Iftekharuddin, Old Dominion Univ. (United States)

We present a method to automatically extract and analyze 3D facial shape using facial curves and curve related geometric features. The geometric features are obtained after transforming the space curve representation to a local coordinate system of the curve itself which makes the features invariant. A vector related to the curve in 3D space can be represented using three orthonormal basis vectors of this local coordinate system. We propose a set of low level geometric features using these orthonormal basis vectors as they characterize the properties of the curve and the geometry of the 3D facial shape as well. Our curve based approach overcomes the curse of dimensionality in comparison with point and surface based analysis of 3D facial shapes. The curve based geometric features represent the variations in local regions of the face which are found effective in classifying and comparing 3D facial shapes. We apply our method in classifying six facial expressions using a publicly available 3D facial expression database. We obtain the Receiver Operating Characteristic (ROC) curves and the area under the ROC curve to evaluate performance of our proposed methods.

9117-49, Session Posters-Tuesday

Comparative analysis of a technique to pick-up 3D hologram data from real object

Dong-Su Lee, Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of); Jung-Young Son, Konyang Univ. (Korea, Republic of); Kwang-Hoon Lee, Korea Photonics Technology Institute (Korea, Republic of)

Holography is one method to record the information from a real scene, but it requires coherent illumination and the lack of resolution of the pick-up device may limit strongly the size of the object that can be recorded. It is also possible to generate a hologram of a real scene in incoherent illumination condition by using techniques likes integral imaging or multiple imaging, but the spatial resolution is usually quite poor. Hologram can be made a scene with a computer, but the heavy computational load limit the size of the scene and it is difficult to create precise models of complicated objects. In this paper, we analyze the different techniques used to pick-up 3D data from a real object like holography or integral imaging. And then, we develop a simulator which would be able to evaluate the key parameters of a 3D image that one can expect to display according to the pick-up system he had used to get the 3D data from a real scene. Then, it may be possible to evaluate their performance and to choose the optimal method one should use according to the resolution, the depth of field or the angle of view he wants to reach.

9117-50, Session Posters-Tuesday

Partially occluded object reconstruction using multiple Kinect sensors

Tabassum Nasrin, Faliu Yi, Samarjit Das, Inkyu Moon, Chosun Univ. (Korea, Republic of)

In this paper, we propose a new method for the partially occluded object reconstruction using multiple Kinect sensors. The quality of occluded object reconstructed from conventional reconstruction method with elemental images captured by common camera arrays in integral imaging is usually degraded due to the existence of occlusion object in the 3D space which is a common case in reality. On the contrary, the Kinect sensors can provide not only RGB images but also depth images. Since the depth and RGB color image is captured by two different cameras on Kinect sensor at different location, the depth image should be mapped to the color image. After image mapping (or registration), the same pixel location on depth and RGB color image would represent the same 3D space point. As result, the depth image after mapping can be used to remove the occlusion object in the corresponding RGB image (or elemental image) before doing object reconstruction in integral imaging. Consequently, the occluded object can be visualized with a high quality and will not take a long time as other methods.

9117-24, Session 6

Interactive holographic display *(Invited Paper)*

Jung-Young Son, Konyang Univ. (Korea, Republic of); Beom-Ryeol Lee, Electronics and Telecommunications Research Institute (Korea, Republic of); Oleksii O. Chernyshov, Volodymyr Gushchyn, Konyang Univ. (Korea, Republic of); Jin-Woong Kim, Electronics and Telecommunications Research Institute (Korea, Republic of)

A holographic display has an ideal property of being an interactive display due to its nature of generating a spatial image with a real volume. However, the image can be hardly viewed due to its small viewing angle and much brighter active surface of the display panel than the image. To overcome this problem and to maximize the spatial image property of the holographic display, a floating imaging optics are combined with the holographic display to make an interactive holographic display. This combining makes the reconstructed image float in front space of the display and hence to allow interacting with users because users can locate the image very easily. This interactive display is also equipped with two flat panel displays which can provide information regarding the reconstructed image and user position detection device for interaction.

9117-25, Session 6

Integral photography capture and electronic holography display *(Invited Paper)*

Yasuyuki Ichihashi, Kenji Yamamoto, National Institute of Information and Communications Technology (Japan)

Our real-time capture and reconstruction system consists of 4K camera by integral photography (IP), optical system for electronic holography, and computing system to up-convert IP images and to generate holograms from up-converted IP images.

The resolution of the IP camera is 4K (3840 x 2160 pixels) and the resolution of liquid crystal display (LCD) panels is 8K (7680 x 4320 pixels). So we performed up-converting the IP images by interpolation of the light information. The number of elemental images of up-converted IP images is 480 x 270, which is quadruple of captured IP images, and the size of each elemental image is 16 x 16 pixels. Up-converting of the IP images and generating the holograms from those IP images were performed by graphics processing units (GPUs) with compute unified device architecture (CUDA). We succeeded in real-time capturing and reconstructing 3D live-scene at 10 frames per second.

Furthermore, our 3D display with electronic holography has a viewing-zone angle of 15 degrees. So we improved the IP camera system so that wide-angle scene is captured by the IP camera. We succeeded in reconstructing wide-angle 3D image and we are generating 3D movie by using improved IP camera now. We also do an experiment in automatic correction of color aberration of the IP images.

9117-26, Session 6

Electronic holography using binary phase modulation *(Invited Paper)*

Osamu Matoba, Kobe Univ. (Japan)

Electronic holography is expected to be an ideal 3D display system. However, there are many problems for the commercially available product. One of the problems is that there is no high potential spatial light modulator (SLM) to handle both amplitude and phase distributions. In electronic holography, there are two ways. One is to display the hologram by using the amplitude modulation in a SLM. In this method, at least half spectral distribution is lost. The other is to use the phase distribution. In this method, lose of amplitude distribution degrades the reconstructed quality. However, it is improved by using a random phase distribution in the original image.

We have been developing electronic holography systems using phase-only distribution. We present numerical and experimental results to discuss the reconstructed quality by using phase distribution. We also discuss how to improve the reconstructed quality.

9117-27, Session 6

Three-dimensional holographic display using ray sampling and integral imaging

Xiao Xiao, Univ. of Connecticut (United States); Koki Wakunami, National Institute of Information and Communications Technology (Japan); Jeho Nam, Jin Soo Kim, Electronics and Telecommunications Research Institute (Korea, Republic of); Bahram Javidi, Univ. of Connecticut (United States)

In this paper, we overview optical reconstruction results of a high-resolution three-dimensional (3D) holographic display system based on dense ray sampling and integral imaging techniques. Holograms are generated based on re-sampling the rays located near the objects from 2D images captured by an integral imaging system. The numerical and optical reconstructed results of the high-resolution holographic display system are shown and compared with conventional integral imaging-based holographic displays for different scenes.

9117-28, Session 7

Depth perception due to captured horizontal motion natural images *(Invited Paper)*

Sumio Yano, Shimane Univ. (Japan)

At first, we examined the optical flow, which is detected by the horizontal motion capture device. In this case, the capture device moves horizontally, and also sights on the fixation point. The scene is simply supposed, namely the upper part of scene is sky, and the lower part of one is land. Using the detected optical flow, we generated the motion parallax images from the random dot pattern. As for this motion parallax images, we confirmed that the depth perception is generated for viewers clearly.

Second, we set up the capture device, which is moved horizontally, and is always trained to the fixation point in the front. Using this equipment, we captured the motion natural images, and also captured another scene without the fixation point. We investigated the depth perception using these natural scene images. In the evaluation, the marker, which supports for the head motion, was added to the images. The results showed that the only horizontal motion natural images did not propose enough depth information.

Third, we made some test images from motion parallax images. The marker was re-arranged, one is delayed 1/4 period?another is 1/2 period. In the case of the 1/2 period, the head position is completely reversed from the one of capture device. The depth perception is changed for the displayed marker position. However, the depth perception in the case of delayed 1/2 period is not so different from the depth perception in the normal head motion.

9117-29, Session 7

Eyetracked optical see-through head-mounted display as an assistive and augmentative communication device *(Invited Paper)*

Hong Hua, Xinda Hu, College of Optical Sciences, The Univ. of Arizona (United States); Chunyu Gao, Augmented Vision, Inc. (United States)

A head-mounted display system with fully-integrated eyetracking capability offers multi-fold benefits, not only to fundamental scientific research but

also to emerging applications of such technology. A key limitation of the state-of-the-art eyetracked head-mounted display (ET-HMD) technology is the lack of compactness and portability. In this paper, we present an innovative design of a high resolution optical see-through ET-HMD system based on freeform optical technology. A prototype system is demonstrated, which offers a goggle-like compact form factor, non-obstructive see-through field of view, true high-definition image resolution for the virtual display, and better than 0.5 arc minute of angular resolution for the see-through view. We will demonstrate the application of the technology as an assistive and augmentative communication device.

9117-30, Session 7

Affective SSVEP BCI to effectively control 3D objects by using a prism array based display

Sungchul Mun, Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of)

3D objects with depth information can provide many benefits to users in education, surgery, and interactions. In particular, many studies have been done to enhance sense of reality in 3D interaction. Viewing and controlling stereoscopic 3D objects with crossed or uncrossed disparities, however, can cause visual fatigue due to the vergence-accommodation conflict generally accepted in 3D research fields. In order to avoid the vergence-accommodation mismatch and provide a strong sense of presence to users, we apply a prism array based display to presenting 3D objects. Emotional pictures were used as visual stimuli in control panels to increase information transfer rate and reduce false positives in controlling 3D objects. Involuntarily motivated selective attention by affective mechanism can enhance steady-state visually evoked potential (SSVEP) amplitude and lead to increased interaction efficiency. More attentional resources are allocated to affective pictures with high valence and arousal levels than to normal visual stimuli such as white-and-black oscillating squares and checkerboards. Among representative BCI control components (i.e., event-related potentials (ERP), event-related (de)synchronization (ERD/ERS), and SSVEP), SSVEP based BCI was chosen in the following reasons. It shows high information transfer rates and takes a few minutes for users to control BCI system while few electrodes are required for obtaining reliable brainwave signals enough to capture users' intention. The proposed BCI methods are expected to enhance sense of reality in 3D space without causing critical visual fatigue to occur. In addition, people who are very susceptible to (auto) stereoscopic 3D may be able to use the affective BCI.

9117-31, Session 7

Full resolution stereoscopic television using flicker-free active beam displacement glasses

Sergey Chestak, Dae-Sik Kim, Samsung Electronics Co., Ltd. (Korea, Republic of)

Two types of stereoscopic television dominate in the consumer market, one based on shutter-glasses, another-on patterned retarder. First type provides full resolution, but is not entirely free of flicker. Second type is flicker-free but reduces vertical resolution by the factor 2. We have devised a stereoscopic system incorporating patterned retarder and new kind of active glasses in order to combine flicker free operation and full resolution. Active glasses are capable of electrically controlled displacement of viewing axis. Each filter of glasses incorporates input polarizer, LC polarization switch and birefringent plate. Viewer, wearing the glasses, always sees only odd lines of the display by the left eye and only even lines by the right eye. Due to the birefringent plate visual position of the lines can be normal or displaced in vertical direction depending on the status of the polarization switch. Distance of the displacement is exactly equal to the lines pitch. By the displaying of full set of the image lines in each two consequent frames and simultaneous switching the polarization switch, full resolution stereoscopic image can be displayed in interlaced manner. Glasses do not provide any flicker. Slow switching of LCD cells does not cause image ghosting. Instead. if the LCD response is very slow, the displayed image degrades to half resolution. Birefringent beam displacer can be made in a form of relatively thick calcite plate or in a form of thin birefringent wedge made of quartz or polymerized liquid crystal.

9117-32, Session 7

Computer simulation of moiré waves in autostereoscopic displays basing on spectral trajectories

Vladimir V. Saveljev, Sung Kyu Kim, Korea Institute of Science and Technology (Korea, Republic of)

The moiré effect is an optical phenomenon which has a negative influence to the image quality; as such, this effect should be avoided or minimized in displays, especially autostereoscoipic three-dimensional ones. This is because of the structure of the multiview autostereoscoipic displays, which typically include two parallel layers with an integer ratio between the cell sizes of these layers. In order to provide the minimization of the moiré effect at finite distances, we developed a theory and computer simulation tools to simulate the behavior of the visible moiré waves in a range of parameters. These include the displacement of an observer and the distance to the screen. Previously [OpEx 20, 2163-2177 (2012)], we made that for the sinusoidal waves; however this was not enough to simulate all real-life situations. Recently, the theory was improved and the non-sinusoidal waves are currently included as well. Correspondingly, the simulation tools are essentially updated. The computer simulation and physical experiment confirm the theory. The typical normalized RMS error is 3 - 5%. In simulation, parameters of the resulting moiré waves are measured semi-automatically. The tools run in two modes, overview and detailed, and can be controlled in an interactive manner. The advanced theory accompanied by renewed simulation tools ensure the minimization and make it convenient.

9117-33, Session 8

Self-referencing digital holographic microscope for dynamic imaging of living cells *(Invited Paper)*

Arun Anand, Vani Chhaniwal, Swapnil Mahajan, Vismay Trivedi, The Maharaja Sayajirao Univ. of Baroda (India); Amardeep S. S. Singh, Rainer A. Leitgeb, Medizinische Univ. Wien (Austria); Bahram Javidi, Univ. of Connecticut (United States)

Digital holographic microscope is an ideal tool for quantitative phase contrast imaging of living cells. It yields the thickness distribution of the object under investigation from a single hologram. From a series of holograms the dynamics of the cell under investigation can be obtained. But two-beam digital holographic microscopes has low temporal stability due to uncorrelated phase changes occurring in the reference and object arms. One way to overcome is to use common path techniques, in which, the reference beam is derived from the object beam itself. Both the beams travel along the same path, increasing the temporal stability of the setup. Self-referencing converts a portion of the object beam is used as the reference beam. It could be achieved by using a glass plate to create two laterally sheared versions of the object beam at the sensor, which interfere to produce the holograms. This leads to a common path setup, leading to high stability (~0.6nm). This technique was used to map cell membrane fluctuations.

9117-34, Session 8

Autostereoscopic 3D display system on the properties of both the expanded depth directional viewing zone and the removed structural crosstalk

Kwang-Hoon Lee, Anjin Park, Dong-Kil Lee, Yang-Gyu Kim, Won-Gun Jang, Youngsik Park, Korea Photonics Technology Institute (Korea, Republic of)

In the optical properties of existing auto-stereoscopic 3D displays with lenticular lens type, one curvature radius on the optical power plan of lenti-let makes one focal length and forms one position of the viewing zone on the depth direction (As the location of the observer). It means that there has the restriction of depth directional freedom of degree to see freely 3D image. Additionally the slanted lenticular lens type induces a crosstalk problem by the structure characteristic between them when the corresponded unit lens-let area are involving the over the area to the total number of views of unit pixels. Thus the crosstalk must be existed in there which cannot remove if any other newly method is would not applied in.

In this paper, we suggested an advanced auto-stereoscopic 3D display system to expand the depth directional freedom of degree and to reduce the crosstalk, which are controlled by both the varying sequential curvatures on the optical power plane of the lenti-let and the construction of lenti-let array formed by the shifted slightly and located on between adjacent rows, in the viewing zone forming optics based on lenticular lens sheet. The former produces the expanding depth regions by the superposed areas formed by each varying focuses on the depth direction to gives the safety stereo image to the observer. The latter produces the crosstalk reduction by removing the structural property such as the corresponded imaging pixel with the parts of adjacent imaging pixels in between the sequential imaging pixel width and the unit lenti-let pitch in the slanted lenticular lens type. Consequently, our approach is one of the quite good candidates to improve and remove the above mentioned problems in ordered. And our validation is performed by the result from the adaptable optical simulation with the partial experiment.

9117-35, Session 8

Properties of a super-multiview image

Beom-Ryeol Lee, Ilkwon Jeong, Electronics and Telecommunications Research Institute (Korea, Republic of); Jung-Young Son, Konyang Univ. (Korea, Republic of)

Super multiview image can provide a continuous parallax. A way of generating continuous parallax is to make at least two different view images get into viewers' each eye simultaneously though it is still not completely comprehensive. The typical viewing zone of supermultiew imaging is not different from those of the contact-type multiview imaging methods such as IP and MV. Hence the property of supermultivew image can be identified in the viewing zone geometries of the methods.

In this paper, the images to be projected to viewers' eyes at the viewing zone are synthesized from multiview images and the visual properties of the synthesized images as the number of the images increases are investigated.

9117-85, Session 8

Display-specific light-field analysis *(Invited Paper)*

Robert Bregovic, Tampere Univ. of Technology (Finland); Péter Kovács, Tibor Balogh, Holografika Kft. (Hungary); Atanas Gotchev, Tampere Univ. of Technology (Finland)

This paper presents an analysis of the 3D visual content cast as light field and aimed at driving the respective light-field displays. Previous generations of 3D displays (e.g. stereoscopic displays, autostereoscopic displays) had very limited number of views, and thus limited parallax. In contrast, the emerging light field displays support hundred(s) of views at resolutions comparable to full HD resolution. These angular and spatial resolutions enable ultra-realistic representation of 3D scenes, for the price of high data throughput, complex data acquisition (sensing) and a high demand of computational power. Thus, the optimization of the content representation is of crucial importance for the performance of the whole display system.

In this paper, we discuss the requirements for light-field based processing of 3D content for representation on the new generation of ultra-realistic light-field displays. We analyze the overall processing chain from sensing (acquisition) through light-field based modeling and representation up to visualization on the considered displays. We give guidelines on how to properly acquire the required data (scene sensing) and repurpose it based on the targeted display and demonstrate how the data should be processed in spatial and frequency domain. We show that by taking into account the properties of the display during scene sensing and during light field processing, a better visual representation of 3D content on a given display can be achieved compared to traditional approaches. The overall process is demonstrated on the state of the art displays produced by Holografika.

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9118-1, Session 1

Large Data Analysis: automatic visual personal identification in demography of 1.2 billion persons *(Invited Paper)*

John Daugman, Univ. of Cambridge (United Kingdom) and Morpho (France)

The largest biometric deployment in history is now underway in India, where the Government is enrolling the iris patterns (among other data) of all 1.2 billion citizens. The purpose of the Unique Identification Authority of India (UIDAI) is to ensure fair access to welfare benefits and entitlements, to reduce fraud, and to enhance social inclusion. Only a minority of citizens in India have bank accounts; only 4 percent have passports; and less than half of all aid money reaches its intended recipients. A person who lacks any means of establishing their identity is excluded from entitlements and does not officially exist; thus the slogan of UIDAI is: "To give the poor an identity." This ambitious program enrols a million people every day, across 36,000 stations run by 83 agencies, with a 3 year completion target for the entire national population. To date almost 500 million persons have been enrolled. In order to detect and prevent duplicate identities, every iris pattern that is enrolled is first compared against all others enrolled so far; thus the daily workflow now requires 500 trillion (or 500 million-million) iris cross-comparisons. Avoiding identity collisions (False Matches) requires high biometric entropy, and achieving the tremendous match speed requires phase bit coding. Both of these requirements are being successfully delivered by wavelet methods developed by the author for encoding and comparing iris patterns, which will be the focus of this presentation.

9118-2, Session 2

Manifolds of large data from different sensory modalities

Ming-Kai Hsu, The George Washington Univ. (United States); Harold Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

A sensing architecture of diverse modalities is a possible solution for real world challenges in both civil and military applications. In many cases, it acquires a large amount of high-dimensional data. How to interpret the underlying phenomenon of the collected data is a key for right solutions. In this paper, we examine the problem of extracting manifolds of large data from different sensory modalities by the concept of dimensionality reduction. Furthermore, we show extensive experiments results on face classifications from Honda/UCSD video database by Isomap, Laplacian Eigenmap and LLE.

9118-3, Session 2

Econometric source LDA discovery by unsupervised learning

Jeffrey C. Jenkins, Rutger van Bergem, George Mason Univ. (United States); Dalila Benachenhou, George Washington University (United States); Harold Szu, The Catholic University of America (United States)

Econometricians generally deal with large data sets that contain more conflated sources than can be handled by current overdetermined macro-economic models. Blind Source Separation could be used to analyze large economic data and provide a better basis to represent economic relationships, which could aid predicting and preempting fluctuations from unknown sources. We observe the Helmholtz free energy principle H=E-TS in capturing variations of open dynamic systems with a firm's cost minimization P=AK^α L^(1-α)-((P_K P_L),[(K L)]^T), and realize the relationship between input/output tradeoffs governed by an outside reservoir. We model the uniformity of an ideal firm by the real positive probability called the Shannon information entropy S, with sources s_1,s_2,...,s_N. We assume a natural mixing of a closed system populated with ideal firms in open thermodynamic subsystems will evolve towards a loss of uniqueness, or maximum entropy driven by interacting discrete firm exchanges. We seek to provide an exemplar of the symbiotic relationship between economic intuition and system dynamics that can foster meaningful knowledge acquisition through LDA learning.

9118-4, Session 3

Phase change nanowire memory *(Invited Paper)*

Ritesh Agarwal, Univ. of Pennsylvania (United States); Yiping Zhao, The Univ. of Georgia (United States)

No Abstract Available

9118-5, Session 3

Recent progresses on nanowires *(Invited Paper)*

Agarwal Ritesh, Univ. of Pennsylvania (United States)

No Abstract Available

9118-6, Session 4

Probing size-dependent light-matter interactions and structural phase change properties with nanowires

Ritesh Agarwal, Univ. of Pennsylvania (United States)

Semiconductor nanowires offer a unique approach for the bottom up assembly of electronic and photonic devices with the potential of integrating different technologies on a common platform. The one-dimensional geometry allows efficient transport of carriers, photons and phonons in a directed manner. We will discuss the intriguing size-dependent properties of one-dimensional semiconductor nanowires at the 20-200 nm lengthscales. At these length-scales not only finite-size effects become important, but also other length-scales such as visible optical wavelengths, strain fields, interfacial, and polarization scales become comparable to the size of the nanostructures. Proper understanding of these phenomena and the effect of different lengthscales on nanowire properties becomes important, which is also required to rationally design functional devices with tunable and precisely controlled responses.

We will discuss size-dependent interaction of light within nanowire optical cavities and their unique waveguiding and slow-light propagation properties and also nanowires integrated with plasmonic nanocavities which allow precise control over their excited state lifetimes, which can be shortened by more than three orders of magnitude to sub-picoseconds due to strong confinement of the optical fields based on the surface plasmon whispering gallery modes. We will also discuss size-dependent structural phase

change phenomena in anowires, which are very important for new types of nonvolatile memory devices. Our recent efforts to observe the crystalline to amorphous phase change in “real time” via in situ electron microscopy techniques will be discussed, which allows unprecedented insights into the critical events that lead to structural phase transformations. The implications of these findings for assembling novel and reconfigurable electronic and photonic devices will be discussed.

9118-7, Session 4

Neuromorphic Implementation of a camera to enhance imaging through fire and smoke *(Invited Paper)*

Jae Cha, A. Lynn Abbott, VPI (United States); Harold Szu, The Catholic Univ. of America (United States); Keith A. Krapels, The Univ. of Memphis (United States); Joseph Landa, BriarTek, Inc. (United States)

Traditional unsupervised LCNN algorithm utilizes iterative optimization process for searching the optimal minimum free energy point. Combined with iterative minimum squared error (MSE) solution techniques for finding the intermediate solution for a transcendental equation, this approach typically results in a doubly iterative loop that is computationally expensive and inefficient. Here, we discuss a new modification of the optimization process based on algebraic approximation function that offers a noniterative solution with reduced loops, which can pave the way to a scalable algorithm suited for a human visual system (HVS)-based massively parallel algorithmic architecture (algotecture). Numerical simulation demonstrates a significant performance improvement over the traditional double loop solution, while maintaining the error below the preset threshold. Implementation on HVS-based algotecture is expected to accomplish several order of speed-up through a fan-in wired diagram while bypassing time-consuming sequential processing.

9118-8, Session 4

Enhancing thermal imaging through large scale fire

Jae H. Cha, A. Lynn Abbott, VPI (United States); Keith A Krapels, The Univ. of Memphis (United States); Harold H Szu, The Catholic Univ. of America (United States)

Professional firefighters combat fires composed of smoke, chemical aerosols and huge temperature variations that obscure vision and hinder their performance.

Currently, a team member carries a single cooled infrared imager of high dynamic range to improve the team’s operational effectiveness in these low visibility of environments. But, for large scale fires each firefighter operates independently to save people and property while overcoming obstacles and hazards. Here we describe a method to equip firefighters with a low-cost, uncooled infrared imager, delivering enhanced vision to each member of the team. This solution improves infrared imagery by using a real-time image processing minus-one algorithm to suppress or remove local obscuring heat sources. We propose to minimize unsupervised free energy in local heat sources, and by blind source de-coupling, present a design of sharper image of low cost IR camera to each firefighter.

9118-9, Session 4

3D printed rapid disaster response *(Invited Paper)*

Edward A. Mottern, Robotic Research LLC (United States)

Under Sensor-smart Affordable Autonomous Robotic Platforms (SAARP) Robotic Research is researching an affordable and adaptable method to implement robotic technology during disaster response. Two platforms are currently being developed that utilize 3D printer technology. These platforms will be built from a set of common components that will allow the later design of other platforms that all share components. This system will provide an affordable and adaptable method for gaining the required robotic technology functionality necessary to address the evolving situations that are encountered during disaster response activities. During disasters new challenges are faced that may require customized tooling or platforms. Instead of prebuilt and prepositioned supplies, a library of validated robotic solutions will be catalogued to satisfy various challenges at the scene. 3D printing components will allow these customized tools to be deployed in a fraction of the time that would normally be required. While the current system is focused on disaster response personnel, this system will be expandable to a range of customers including domestic law enforcement, the Armed Services, universities, and research facilities.

9118-10, Session 4

3D printing nanotech enhanced by quantum mechanics *(Invited Paper)*

Harold Szu, The Catholic Univ. of America (United States); Jeffery C. Jenkins, George Mason Univ. (United States); Jerry Wu, The Catholic Univ. of America (United States)

3D nnao-printing, or additive manufacturing, is a process of making a three-dimensional solid object of virtually any shape from a digital model with quantum dots elementary material. Sequential additive processes differ from the method used to produce the ‘layering’ effect of material, in the following three aspects.

9118-11, Session 4

Wavelet techniques for the detection of silicone on rough aluminum substrates by machine analysis of mid-infrared spectra

Richard Fauconier, Block Engineering, LLC (United States)

A method for machine analysis of infrared spectra is presented that blends the expertise of the spectroscopist with the outputs of common wavelet transforms in a single algorithm. The reflectance spectra are those of silicone oil on rough aluminum substrates. A widely tuned quantum cascade laser operating in the mid-infrared region provided the irradiance for this automated real-time spectroscopy. Depending on the thickness of the silicone deposit and the angle of incidence at which the deposit is irradiated, the maxima and minima of the spectra can shift appreciably, and/or the spectra may assume different shapes. The recognition algorithm detected the presence of silicone in all of these circumstances. For the amounts of silicone applied and angles of incidence for the interrogating radiation, two variants of a specularly distorted spectrum, and two variants of a simple absorbance spectrum were found. Pertinent details of how the wavelet transforms are exploited are presented, and their use in machine recognition of silicone by its mid-infrared spectra is demonstrated. Three of the spectral variants were successfully identified by using, in conjunction with the continuous wavelet transform, the Gauss-1 wavelet, a time-reversed version of the same, and an inverted Mexican Hat wavelet. The fourth spectral variant was identified with a symlet-6 wavelet in conjunction with a scale-time energy-distribution analysis across various levels of a multiresolution analysis. Robust recognition of silicone on rough aluminum substrates is achieved with an algorithm that seamlessly combines the detection of all four spectral variants.

9118-12, Session 4

Highway 3D model from image and lidar data *(Invited Paper)*

Henry Chu, Jinfeng Chen, Xiaoduan Sun, Univ. of Louisiana at Lafayette (United States)

Three-dimensional models can enable highway engineers to design and evaluate highway infrastructures from new perspectives, which are not feasible with the current available technologies. We devised techniques to integrate airborne LiDAR data with highway video data collected from a driver's perspective into a 3-D model of the road and the roadside elements. The main development tasks are (i) to identify the groundplane in the video data and then further segment that plane into traffic lanes and shoulder areas; and (ii) to convert the data extracted from (i) into 3-D models using the geometry and parameters of the image/video acquisition and LIDAR data, such as to detect sign posts and guardrails when they are present and to integrate the model into a geographic information system, as follow-up work. The image data is placed in the 3D world coordinates by extracting the Road Coordinates of the camera positions stored during the image data acquisition process. From the LiDAR data, we detected highway segments as well as other objects such as trees, buildings, and ditches. Finally we integrated the two data streams using the camera coordinate system to form the 3D environment.

9118-13, Session 5

Sparse MRI: the application of compressed sensing for rapid MRI *(Invited Paper)*

Michael Lustig, Univ. of California, Berkeley (United States)

MRI is en excellent imaging modality. However it suffers from slow data acquisition rates. Since it invention more than 30 years ago improvements in hardware and imaging techniques have enabled faster data collection. However, we are currently at the point where fundamental physical and physiological effects limit our ability to simply encode data more quickly.

This fundamental limit has led many researchers to look for methods to reduce the amount of acquired data without degrading the image quality. These reduced sampling methods are based on the fact that MRI data is redundant, so the underlying information may be extracted from less data than traditionally considered necessary. A source of redundancy that has been gaining significant attention is the sparsity and compressibility of various MR signals. This effort has been motivated by the recent introduction of the theory of compressed sensing (CS).

CS is a new sampling theory for compressible signals that allows sampling at rates much lower than the Nyquist-rate. CS implicitly compresses data within the signal acquisition process by obtaining fewer so-called "incoherent measurements". The practical result of CS in the context of MRI is that MR images require much less data for reconstruction, and hence can be scanned much faster.

The purpose of the talk is cover the basics of compressed sensing theory in the context of MRI and to survey current status and trends in using compressed sensing for clinical applications.

9118-15, Session 6

Compressive imaging: quantization and rate-allocation *(Invited Paper)*

Amit Ashok, College of Optical Sciences, The Univ. of Arizona (United States); Yuzhang Lin, The Univ. of Arizona (United States)

Compressive imaging typically counts the number of measurements relative to scene dimensionality to provide a measure of compression. However, for data storage and transmission purpose compressive measurements need to be quantized. In this work we consider compressive measurement quantization and rate-allocation for different compressive measurements such as random and information-optimal designs. Specifically, we employ the Lloyd-Max scalar quantizer and a power-law signal model based rate-allocation scheme to quantify the performance of compressive imaging for a variety of natural scenes. The relative performance of compressive imaging and traditional image compression algorithms, such as JPEG2000, is analyzed for different system parameters such as measurement signal-to-noise-ratio (SNR) and compression rate. We find that in low and medium SNR, compressive imaging provides superior and comparative image fidelity relative to traditional image compression algorithms. However in the high measurement SNR regime the traditional image compression yields significantly higher image fidelity relative to compressive imaging. We also discuss the relative system size, weight and power complexity of compressive imaging and traditional image compression system implementations.

9118-16, Session 6

Optimal filter design for compressive sensing in electrogastrogram (EGG) *(Invited Paper)*

Ning Xi, Michigan State Univ. (United States)

Unlike traditional Analog-to-Digital Conversion (ADC), the main idea of Analog-to-Information Conversion (AIC) is to sample signal utilizing the information that the signal has a sparse representation in some dictionary. Kirolos et al. in Rice University proposed an AIC scheme based on compressed sensing in 2006: first demodulation, second analog filtering, and finally uniform sampling. The motivation of such a scheme is to lower the sampling rate without loss of signal information. However, in other words, under the same sampling rate, the sparsity information would help us reveal more detail of the signal.

The Electrogastrogram (EGG) signal meets the requirement of the model of the AIC scheme: 1) it is sparse in some domain, e.g. frequency domain; 2) it can be modeled as a typical linear system, i.e. a plant dynamic equation and a measurement equation, in the sparse domain. Our progress on the whole AIC scheme for EGG applications is the denoising method. For a typical linear system, the well-known Kalman filter is the optimal Minimum Mean-Square Error (MMSE) state estimator; however, under the compressed sensing context, because the observability of the system cannot be satisfied, the Kalman filter will diverge. Thus we propose a novel method to solve this problem.

It is not the first time for combining the Kalman filter and the compressed sensing. Vaswani et al. proposed a Kalman filtered compressed sensing scheme in 2008. Their main idea is to estimate the support of the signal first and then the Kalman filtering only affects the supports. Our scheme improves the generality of the model. Basically, the Kalman filter is the filtering method utilizing the system model information. What we need is just using both the information of the system model and the information of sparsity to denoise. To achieve this goal, we design an optimal problem based on the equivalent Kalman filtering model without any statistical term. This equivalent model is actually a least square problem for the plant noise and the measurement noise in the system model. By adding an L1-norm term into the optimal problem, the sparsity information can be then naturally integrated to the system model information.

Simulations show that this novel optimal problem can balance the model and sparse information well. However the complexity of the calculation is high as it grows with time. Thus, the future work is to figure out a recursive calculation method, which only needs to solve a constant scale sub-problem at each new time moment, just like what the Kalman filter had done.

9118-17, Session 6

Noninvasive scalp pair correlation functions electroencephalogram (EEG) *(Invited Paper)*

Francois Lalonde, Nitin Gogtay, National Institutes of Health (United States); Binh Q. Tran, Charles C. Hsu, Jefferson Willey, Jerry Wu, Gyu Moon, Joseph S. Landa, François Carlo Morabito, Yuh-Show Tsai, The Catholic Univ. of America (United States); T.-P. Jung, C. T. Lin, Univ. of California, San Diego (United States); Harold H. Szu, Alan T. Krzywicki, Babajide O. Familoni, Keith A. Krapels, U.S. Army RDECOM, NVESD (United States)

We apply a smart algorithm to capture compressive sensing high density brain wave EEG for the detection and treatment of Brain Order Disorder (BOD) transitions conveniently, e.g. sport brain injury-blood clot, fever; to axon erosion; senior cognitive decline, as well as juvenile Children Onset of Schizophrenia (COS), and adult Post Traumatic Stress Disorder (PTSD). NEW DESIGN: EEG information resides in the brain's Frontal, Parietal, Temporal, and Occipital lobes of each hemisphere. We designed a new high-density design of micro-(gecko feet like)-dry-electrodes N~O(10^(2+3)) covering the whole head scalp with a non-tethered, wearable cap. Both the average and fluctuating EEG electric potentials, e_s=e =_s+e =_s, are received and processed by the wearer's personal Smartphone type device. This will allow a distributed "Points-of-Care" testing approach for patient homecare, with rapid transmittal of data and fewer clinic visits complement the patient telemetry both outside and inside medical facilities.

Moreover, Instead of 3-D FFTs, we employ 1-D space-filling Hilbert-Peano s-curve, preserving the local neighborhood relationship for rapid compressive sensing (CS). We use 1-D FFT sorting EEG's in sparser frequency bins to facilitate m sparse linear combinations, m<< N, for wireless CS readout. While physicians utilize the average e =_s of all N electrodes, we can efficiently compute the N^2 pair-electrodes correlation of fluctuations < e =_s +e =^'=_s> by Wiener-Khinchin-Einstein formula.

We amend the clinic test & evaluation Protocol supplementing the Children Onset Schizophrenia, with the Electroencephalogram (EEG) noninvasive reading on scalp electrodes (FDA Device #3), sampled following patient telemetry protocol both outside and inside medical facilities."

9118-18, Session 6

Overcoming shadowing occlusion by compressive sensing *(Invited Paper)*

Harold Szu, The Catholic Univ. of America (United States); Charles C. Hsu, The George Washington Univ. (United States); Todd W. DuBosq, Univ. of Central Florida (United States); Steven K. Moyer, The Catholic Univ. of America (United States); Bavinder Kaur, George Mason Univ. (United States); Kelvin R. Leonard, Christopher M. May, The Catholic Univ. of America (United States); Keith A. Krapels, The Univ. of Tennessee Health Science Ctr. (United States); Joseph S. Landa, BriarTek, Inc. (United States)

The active EOIR&RF imaging often suffered the line of sight occlusion, shadowing, and motion blur. For such a corrupted or missing pixels, we explored error–resilient analytical continuation method combined with CRT&D compressive sensing (CS). We map 3-D to 1-D space-filling curve preserving the neighborhood proximity, where a 1-D windowed FFT or Wavelet Transform could generate a sparse space-frequency (x-f) joint representation. Then, CRT &D purely random zero-one filter was applied at the sparse (x-f) representation. We preserved local randomness property, while vary the sparseness from region to region for our different requirement in high frequency. In other words, we move ones and zeros respectively around in each region for the need of the information acquisition and the error resilience.

We proved the inverse CS linear programming can cover a graceful degradation. It turned out that the restoration was comparable to the percentage of missing pixels (3% ~5%) suffered in 3-D active LIDAR imagery near the edges, that proved to be detrimental to human visual perception. Design of COTS is given combining laser pointer pen with fan-in collector and pen-knob housing smart algorithm processor.

9118-26, Session 6

Split Bregman's optimization method for image construction in compressive sensing *(Invited Paper)*

Anke Meyer-Bäse, Simon Foo, Dana Skinner, Florida State Univ. (United States)

The theory of compressive sampling (CS) was reintroduced by Candes, Romberg and Tao, and D. Donoho in 2006. Using a priori knowledge that a signal is sparse, it has been mathematically proven that CS can defy Nyquist sampling theorem. Theoretically, reconstruction of a CS image relies on the minimization and optimization techniques to solve this complex almost NP-complete problem. There are many paths to consider when compressing and reconstructing an image but these methods have remained untested and unclear on natural images, such as underwater sonar images. The goal of this research is to perfectly reconstruct the original sonar image from a sparse signal while maintaining pertinent information, such as mine-like object, in Side-scan sonar (SSS) images. Goldstein and Osherhave shown how to use an iterative method to reconstruct the original image through a method called Split Bregman's iteration. This method "decouples" the energies using portions of the energy from both the l1 and l2 norm. Once the energies are split, Bregman iteration is used to solve the unconstrained optimization problem by recursively solving the problems simultaneously. The faster these two steps or energies can be solved then the faster the overall method becomes. While the majority of CS research is still focused on the medical field, this paper will demonstrate the effectiveness ofthe Split Bregman'smethods on sonar images.

9118-19, Session 7

Unsupervised learning toward brain imaging data analysis *(Invited Paper)*

Jong-Hwan Lee, Korea Univ. (Korea, Republic of)

In this talk, I would like to introduce our recent works on the brain imaging data analysis applying unsupervised learning methods. We have been proposed several methodological applications of unsupervised learning algorithms including an (1) independent vector analysis and (2) iterative dual-regression approach as an extension toward a temporal-concatenation based independent component analysis to analyze a group of functional magnetic resonance imaging (fMRI) data sets acquired from multiple subjects. To get accurate neuronal activation maps from group fMRI data, neuronal activation maps from each of multiple subjects need to be correctly estimated and our works from the following two studies are drawn in this context. First, a method to correctly estimate individual neuronal activations from group fMRI data from multiple subjects was addressed applying an independent vector analysis (IVA). Using an IVA approach, spatially dependent neuronal activation patterns across multiple subjects were successfully estimated in each independent vector (IV) component, while maintaining the independence across multiple IVs. Second, an approach to fine tune individual neuronal activations estimated from a temporal-concatenation based group ICA method was proposed deploying an iterative approach of spatial-temporal regression of the neuronal activations to maximally fit into the fMRI data of corresponding individual.

9118-20, Session 8

User authentication systems based on brain finger-prints *(Invited Paper)*

Soo-Young Lee, Eunsoo Jung, KAIST (Korea, Republic of)

We propose to use EEG signals to make user authentication for requiring high security. EEG signals were measured while the subjects saw several images in sequences. Since subject's EEG signals are different for known and unknown images, these EEG sequences may be used to identify beach

subject. Correlation analysis and classification results shows the feasibility of user authentication from EEG signals.

9118-21, Session 8

Fixing basis mismatch via alternating convex search

Jonathan M. Nichols, U.S. Naval Research Lab. (United States); Albert Oh, Duke Univ. (United States); Rebecca Willett, Univ. of Wisconsin-Madison (United States)

The theory behind compressive sampling pre-supposes that a given sequence of observations may be exactly represented by a linear combination of a small number of basis vectors. In practice, however, even small deviations from an exact signal model can result in dramatic increases in estimation errors, the so-called “basis mismatch” problem. This work provides one possible solution to this problem in the form of an iterative, biconvex search algorithm. The approach uses the standard l1-minimization to find the signal model coefficients followed by a maximum likelihood estimate of the signal model. The process is repeated until a convergence criterion is met. The algorithm is illustrated on harmonic signals of varying sparsity.

9118-22, Session 8

Detecting directional and spectral characteristics of anomalous radiation sources

Benjamin Manning, Wojciech Czaja, Thomas McCullough, Univ. of Maryland, College Park (United States); Lance McLean, National Security Technologies, LLC (United States)

OSCAR (Occluding Six Crystal ARay) is a configuration of six sodium iodide scintillators arranged in a hexagon to give six modes of detection for the purpose of detecting the angular response of real world radiation sources. We are particularly interested in recovering the direction and, to an extent, the complete spatial information of well localized anomalous radiation sources.

We present a fast numerically stable algorithm for recovering directional information of radiation sources. This algorithm works in near real time and operates autonomously, providing actionable feedback to identify potential threats and their characteristics.

Our approach utilizes a new class of composite dilation wavelets, designed in line with symmetries of OSCAR. These wavelets use a non-commutative crystallographic group of shifts. This group contains the symmetry group of the OSCAR geometry and extends beyond the usual commutative group of integer translates which do not respect the symmetry of the OSCAR system. This yields a sparse representation of localized anomalous radiation sources along with sparse representations of large scale background radiation.

We model OSCAR’s response to monoenergenic sources using Monte Carlo radiation transport code. This, combined with the wavelet decomposition of spatial and energy space, gives a dictionary that sparsely represents the response of the OSCAR from any real world scenario. We then use compressed sensing techniques to recover the spatial distribution of radiation sources with the emphasis on recovering the direction and spectra of well localized sources.

9118-23, Session 8

Low-discrepancy sampling of parametric surface using adaptive space-filling curves

Charles C. Hsu, Trident Systems Inc. (United States); Harold Szu, The Catholic Univ. of America (United States)

Low-discrepancy point distributions exhibit excellent uniformity properties for sampling in applications such as smartphone-based electroencephalogram (EEG) system for homecare applications. In this paper, we discuss a number of algorithms for generating effective low-discrepancy point distributions on arbitrary parametric surfaces using the idea of converting the 2D sampling problem into a 1D problem by adaptively mapping a space-filling curve onto the surface. Peano curve is a densely self-intersecting curve to construct a continuous mapping from a higher dimensional hypercube to 1 dimensionality. Hilbert curve is a continuous fractal space-filling curve to effectively preserve locality. Both space-filling curves will be analyzed and their results will be applied to the homecare applications of the EEG system.

9118-24, Session 8

SAR GMTI technologies and their applications

Charles C. Hsu, Trident Systems Inc. (United States); Harold Szu, The Catholic Univ. of America (United States)

SAR (Synthetic Aperture Radar) and GMTI (Ground Moving Target Indicator) technologies provide U.S. forces results from its unique ability to distinguish targets moving on land or water from surface clutter over a large area in bad weather and darkness by virtue of the Doppler radar return of the moving targets. SAR is an active sensor to transmitting its own RF energy (such as a frequency chirp), and then measure the echoed return scattered by the surface on the ground. Technically, SAR processing is the transformation of raw SAR signal data into a spatial image. GMTI is a remote sensing process using multiple channels of RF data to minimize the effects of interference patterns and ground clutter and to recognize and extract targets on the ground. In this paper, research interest is primarily focused on using SAR change detection for detecting moving targets in regimes for slow-moving targets in nonhomogeneous clutter. Specific interests include continuous detection, geolocation, and tracking.

9118-42, Session 8

Probabilistic inequalities with applications to machine learning

Xinjia Chen, Southern Univ. and A&M College (United States)

We propose a new approach for deriving probabilistic inequalities based on bounding likelihood ratios. We demonstrate that this approach is more general and powerful than the classical method frequently used for deriving concentration inequalities such as Chernoff bounds. We have derived new concentration inequalities using the proposed approach, which have important applications in machine learning.

9118-14, Session 10

A minimum invasive and maximum specific neo-Angiogenesis biomarker of a time-reversal spectral image tracking toward malignant breast/skin cancer *(Invited Paper)*

Harold H. Szu, The Catholic Univ. of America (United States); Nadarajen A. Vydelingum, National Cancer Institute (United States); Philip P. Hoekstra III, Therma-Scan, Inc. (United States); Joseph S. Landa, BriarTek, Inc. (United States); Charles C. Hsu, George Washington Univ. (United States); Liyi Dai, Harvard Univ. (United States); David G. Brown, U.S. Food and Drug Administration (United States)

In compressive sensing, various methods have been proposed to recover a vector of sparse signals x from a linear measurement model $y = Ax$. Because the linear model is often an approximation for problems of practical interest, the robustness of signal recovery solutions in the presence of uncertainties is a basic issue in the compressive sensing framework. In this paper, we describe several recent results pertaining to the robustness of sparse signal recovery solutions. The first is the sensitivity analysis of compressive sensing solutions to perturbations in the linear model. An exact formula for sensitivity analysis is provided. Algorithms for sensitivity reduction are designed. Furthermore, algorithms for obtaining robust compressive sensing solutions under the worst-case perturbations are derived through the Alternating Direction Method of Multipliers. The effectiveness of the algorithms for improving the solution robustness is illustrated using a numerical example.

9118-27, Session 10

Authentication, privacy and security can exploit brainwaves by smartphone *(Invited Paper)*

Jeffrey C. Jenkins, Charles Sweet, Loft Mind, Inc. (United States); James Sweet, Loft Mind, Inc. (Germany); Harold Szu, The Catholic Univ. of America (United States)

In Authentication, Privacy and Security (APS) disciplines, the brainwave among all other well known biometrics has never been exploited. We apply wireless EGG Smartphone (Szu, et al. J. CIS 2013) to augment current digital User Access Control (UAC) and verification systems with an additional layer of security using non-tethered Electroencephalogram (EEG) devices. The aim of hardening UAC verification is not only beneficial for soft biometric enhancement of computer terminal security, but may also serve to provide the medical and mental health communities with a tool to measure fluctuations in an individual's mental performance baseline over time. Towards that goal, we describe an infrastructure that supports distributed verification for web-based EEG authentication and the performance metrics required for access to web content. A user attempting to gain access to digital content protected by EEG-UAC soft biometrics shall perform a series of sensory evoked memory recall perception tests. A series of N random images are shown with an embedded set of M randomly placed personal images provided by the user at a rate of 1.25 Hz. While the images are being displayed, we collect the user's wireless head mounted EEG output, which are indications of relative amplitudes of the individual EEG frequency bands (alpha, beta, gamma, theta, delta). To provide an upper bound on mental processing time, the user was instructed to click a mouse when seeing one of their images. We assert that the difference in time (T_t-T_0)=T = between seeing an image and clicking a mouse in response will statistically converge to an upper bound for a physical hand-eye coordination reaction. This reaction time T =_R contains within it a vector of separate time series which also revert to a mean value with low variance. We begin by discussing the EEG and other brain monitoring devices, and current UAC systems. Then, we demonstrate the signal processing procedure to predict the next reaction fluctuation time. Results of the single and multiple user access and denial ROC curve is demonstrated, and results of simulated "attacks" on user login data is performed. We then describe applications of this work to enhance security of web-based UAC, and interfacing with control of other electronic devices.

9118-28, Session 10

Heart rate variability (HRV): an indicator of stress

Balvinder Kaur, Joseph J. Durek, Barbara L. O'Kane, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Vasiliki N. Ikonomidou, George Mason Univ. (United States)

Heart rate variability (HRV) is an important indicator of several conditions that affect the autonomic nervous system, including traumatic brain injury, post-traumatic stress disorder and peripheral neuropathy [1, 6, 7]. Recent work has shown initial progress in establishing a relationship between HRV features and subject's mental state [2, 10]. Although a variety of time and frequency domain classifiers have been investigated, the observation of the relationship generally requires long observation times that are not necessarily practical in dynamic settings. In this paper, we use Electrocardiogram (ECG) time series collected during normal and stressed conditions, produced by means of the Trier social stress test and the Stroop effect test, to compute HRV driven features and quantify the ability of a set of classification algorithms to distinguish stressed from normal conditions. To classify RR-intervals, we explored classification algorithms that are commonly used for medical applications such as 1) logistic regression [9], 2) least square discriminant analysis (LDA) [3], 3) artificial neural network [4], and 4) support vector machines (SVM) [4]. Classification performance was quantified by means of precision, sensitivity and specificity; ROC curves are generated. Results from each classifier are then compared to find the optimal classifier and HRV features for stress detection. This work, collected under an approved protocol, not only provides a method for developing models and classifiers based on human data, but also provides a foundation for a stress indicator tool based on potential HRV. Further, developed classification tools will not only benefit many medical applications for detecting stress, but also many security and military applications for screening such as: border patrol, stress detection for deception [1, 10], and wounded-warrior triage [8].

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9118-29, Session 10

Impact of human emotions on physiological characteristics

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Human emotions and their impact on physiological characteristics are researched and discussed in this article. Nowadays there are many applications for which information about the emotional state is important in many fields. Increase the accuracy and simplicity of systems for the classification of emotional states is necessary for full utilization of such a system. Information about the emotional state is in today's applications received by voice or facial mimicry. This research has focused mainly on voice compared with brain activity. Our research is based on an examination of physiological changes in the patient and compared these changes with the vocalization. The patient was stimulated by psychological methods in the normal calm state. In this condition, the patient reads text and speech activity are recorded. The same process is also performed after the patient is stimulated in the stress state. Number of measured patients was 30. Emotional activities were captured using electroencephalography (EEG), electrocardiography (ECG), samples of cortisol level and parameters of speech expression. Because EEG measurement is very sensitive to changes in power supply, all 30 measurements were carried out in the EMC chamber to remove unwanted electromagnetic interference. Classifier of emotional state is an artificial neural network whose inputs are extracted speech parameters are the fundamental frequency of human speech, Cepstral coefficients and others parameters of physiological activity of the brain. This article presents a new perspective for the classification of emotional state of man of his speech and physiological changes.

9118-30, Session 10

Neural network classifier of attacks in IP telephony

Jakub Safarik, Miroslav Voznak, Miralem Mehic, Pavol Partila, Martin Mikulec, VŠB-Technical Univ. of Ostrava (Czech Republic)

Various types of monitoring mechanism allow us to detect and monitor behavior of attackers in VoIP networks. Analysis of detected malicious traffic is crucial for further investigation and hardening the network. This analysis is typically based on statistical methods and the article brings a solution based on neural network. The proposed algorithm is used as a classifier of attacks in a distributed monitoring network of independent honeypot probes. Information about attacks on these honeypots is collected on a centralized server and then classified. This classification is based on different mechanisms. One of them is based on the multilayer perceptron neural network. The article describes inner structure of used neural network and also information about implementation of this network. The learning set for this neural network is based on real attack data collected from IP telephony honeypot called Dionaea. We prepare the learning set from real attack data after collecting, cleaning and aggregation of this information. After proper learning is the neural network capable to classify 6 types of most commonly used VoIP attacks. Using neural network classifier brings more accurate attack classification in a distributed system of honeypots. With this approach is possible to detect malicious behavior in a different part of networks, which are logically or geographically divided and use the information from one network to harden security in other networks. Centralized server for distributed set of nodes serves not only as a collector and classifier of attack data, but also as a mechanism for generating a precaution steps against attacks.

9118-31, Session 10

Predictive model for determining the quality of a call

Miroslav Voznak, Technical Univ of Ostrava (Czech Republic); Jan Rozhon, Pavol Partila, Jakub Safarik, Martin Mikulec, Miralem Mehic, VŠB-Technical Univ. of Ostrava (Czech Republic)

This paper deals with the methodology and experimental implementation of the system for the speech quality prediction in IP networks, which in our days form the backbone of modern communications. The fundamental impact of qualitative parameters of the IP networks such as network delay, delay variation (jitter) and packet loss on the speech quality as it is perceived by the end users is studied. Based on this study a model for nonintrusive speech quality estimation was developed utilizing the knowledge about the current network state as it is reported by probing software. This model is built upon the neural networks and it allows for a successful, efficient and accurate speech quality prediction with high conformity with the results of the PESQ algorithm. The actual conformance with the PESQ algorithm, the results of which form the basis for the neural network training, is studied in this paper as well to testify the high precision of the proposed model in estimating this industry standard in the field of objective speech quality measurements. The final part of the paper describes the actual experimental implementation of this model using some of the well-known simulation tools so that the reader of this paper can easily deploy the measuring platform as it is described here. The main contribution of this paper lies in the model for speech quality estimation, which makes it possible to obtain the information about the speech quality without the need of actually performing the call.

9118-32, Session 12

Using Computer Algebra and SMT Solvers in Algebraic Biology

Mateo Pineda Osorio, Univ. EAFIT (Colombia)

Biologic processes are represented as Boolean networks, in a discrete time. The dynamics within these networks are approached with the help of SMT Solvers and the use of computer algebra. Software such as Maple and Z3 was used in this case. The number of stationary states for each network was calculated. The network studied here corresponds to the immune system under the effects of drastic mood changes. Mood is considered as a Boolean variable that affects the entire dynamics of the immune system, changing the Boolean satisfiability and the number of stationary states of the immune network. Results obtained show Z3's great potential as a SMT Solver. Some of these results were verified in Maple, even though it showed not to be as suitable for the problem approach. The solving code was constructed using Z3-Python and Z3-SMT-LiB. Results obtained are important in biology systems and are expected to help in the design of immune therapies. As a future line of research, more complex Boolean network representations of the immune system as well as the whole psychological apparatus are suggested.

9118-33, Session 12

Telescopic augmented reality at nanoscale

Jeffrey C. Jenkins, George Mason Univ. (United States); Harold Szu, The Catholic Univ. of America (United States)

In this paper, we describe a consistent macroscopic (cm-scale), mesoscopic (micron-scale), and microscopic (nano-scale) approach to enable telescopic multiple resolution (TMR) of current Augmented Reality (AR) technology. We proposed to augment AR-TMR by adding a new energy-matter interaction engine based on Quantum Mechanics (QM) and Quantum Computing (QC). The interactions must be realistic Einstein photoelectric effect (EPE), regardless of the view point. Einstein was puzzled why quantized photon energy $E=n\hbar\omega;n=\text{integers},\omega=2\pi f$, can produce after photoelectric surface interaction a continuous analog electric charge current density $j\ =pqv$. Note that a constant Einstein speed of light $C\_o=f\lambda$; then $\lambda=1\mu$ at MWIR has exactly 1 eV photon energy and has frequency f=300 THz. Some of the molecular electrons involved in a chemical interaction have about a eV of binding energy. As such, Tera-Hz radiation would be absorbed and scattered, unable to propagate through the atmospheric molecules. To achieve such a TMR AR, we provide a virtual telescope consistent algorithm for viewing 3D physics and/or chemical interactions at a point in space, with an arbitrary MRA field of view. To illustrate the algorithm, we consider the EPE, including nano-scale quantum mechanics effects. These effects model the interaction between particles and photons at the microscopic level, considering the properties of de Broglie-Bohm photon wave packet emitted from a source, as well as the molecular properties of a surface that is in

the path of the wave packet in a 3D environment. We propose a stochastic method of updating the visual and material properties of point-wise interactions to enable dynamic rendering. To view the effect of microscopic interactions in a macroscopic viewpoint, (i.e. simulating a fire with polygonal structure which is able to deform intersecting 3D object faces), we describe a new stage of the rendering pipeline which uses Quantum-Dot Cellular Automata (QCA) to simulate the structural propagation of energy changes from point-wise microscale interactions upwards to the larger mesoscopic structure. Furthermore, the mesoscopic behavior can be extended to modify the 3D structure of a macroscopic object by dynamic deformation, driven by a relational database (lookup table) approach to progressive material mapping. Our method of texture mapping includes a separate channel of the surface boundary condition (molecular structure, density, etc.) of each 3D point in the environment, which receives updates from the preceding two behavioral scales. We demonstrate the results of implementing this addition to the AR rendering pipeline via for the photoelectric effect, and conclude by describing areas of future work and application for quantum rendering algorithms.

9118-34, Session 12

Experimental verification of the performance of artificial neural networks (ANNs) versus partial least squares (PLS) for spectral interference correction in optical emission spectrometry

(Invited Paper)

Z. Li, X. Zhang, Vassili Karanassios, Univ. of Waterloo (Canada)

Regardless of the number of grooves/mm of the grating used, in atomic emission spectrometry, a spectrometer with a long focal length (e.g., 0.5 m to 0.75 m) is required in order to obtain resolution of <100 pm. Such a resolution is essential in order to address (but not completely eliminate) spectral overlaps (often called spectral interference effects). Due to their size and weight (on account of their long focal length), such spectrometers cannot be used for taking "the lab to the sample" type of applications. Spectral overlaps become progressively more severe as the focal length of the spectrometer is decreased, for example down to 12-15 cm. Short focal length spectrometers (translating to small size) are better suited for portable chemical measurements in the field. Although increasing the number of grooves/mm used in small focal length spectrometers appears to be appealing, there are fundamental limits to such a suggestion. Interesting alternatives arise by considering use of artificial neural networks or of statistical (or mathematical) methods to address spectral overlaps. In this presentation, statistical and neural network-based methods will be compared and contrasted using actual experimental results (rather than mostly simulations that were previously reported).

9118-35, Session 12

Analyzing toys models of Arabidopsis and Drosphila using Z3 SMT-LIB

Martin Rodriguez, Univ. EAFIT (Colombia)

Toy models for the Arabidopsis Taliana flower and the Drosophila are analyzed using Microsoft SMT-Solver Z3 with the SMT-LIB language. The models are formulated as Boolean networks which describe the metabolic cycles for Arabidopsis and Drosophila. The dynamic activation of the different bio macromolecules is described by the variables and laws of Boolean transition. Specifically, bitvectors and assertions, which describe the change of state of bitvectors from a sampling time to the next, are used. The dynamic feasibility problem of the biological network is translated to a Boolean satisfiability problem. The corresponding dynamic attractors are represented as a model of satisfiability. The Z3 software allows all required computations in a friendly and efficient manner. It is expected that the SMT-solvers, such as Z3, will become a routine tool in system biology and that they will provide bio-nanosystem design techniques. As a line for future research, the study of the models for Arabidopsis and Drosophila using different SMT-solvers such as CVC4, Mathsat and Yices, is proposed.

9118-36, Session 12

Solving a discrete model of the lac operon using Z3

Natalia A. Gutierrez, Univ. EAFIT (Colombia)

A discrete model for the Lcac Operon is solved using the SMT-solver Z3. Traditionally the Lac Operon is formulated in a continuous math model. This model is a system of ordinary differential equations. Here, it was considered as a discrete model, based on a Boolean red. The biological problem of Lac Operon is enunciated as a problem of Boolean satisfiability, and it is solved using an STM-solver named Z3. Z3 is a powerful solver that allows understanding the basic dynamic of the Lac Operon in an easier and more efficient way. The multi-stability of the Lac Operon can be easily computed with Z3. The code that solves the Boolean red can be written in Python language or SMT-Lib language. Both languages were used in local version of the program as online version of Z3. For future investigations it is proposed to solve the Boolean red of Lac Operon using others SMT-solvers as cvc4, alt-ergo, mathsat and yices.

9118-37, Session 12

Using Tutte polynomials to analyze the structure of the benzodiazepines

Juan José Cadavid Muñoz, Univ. EAFIT (Colombia)

Graph theory in general and Tutte polynomials in particular, are implemented for analyzing the chemical structure of the benzodiazepines. Similarity analysis are used with the Tutte polynomials for finding other molecules that are similar to the benzodiazepines and therefore that might show similar psycho-active actions for medical purpose, in order to evade the drawbacks associated to the benzodiazepines based medicine. For each type of benzodiazepines, Tutte polynomials are computed and some numeric characteristics are obtained, such as the number of spanning trees and the number of spanning forests. Computations are done using the computer algebra Maple's GraphTheory package. The obtained analytical results are of great importance in pharmaceutical engineering. As a future research line, the usage of the chemistry computational program named Spartan, will be used to extent and compare it with the obtained results from the Tutte polynomials of benzodiazepines.

9118-38, Session 12

Analytical resolution of the reactive diffusion equation for transient electronics including materials whose porosity value changes in terms of their thickness

Agustín Vargas Toro, Univ. EAFIT (Colombia)

Transient Electronics is a new development in technology whose main characteristic is that its components can disappear in a programmed and controlled way, which means such devices have a pre-engineered service life. Nowadays, there is a huge field of application employing Transient Electronics, involving the reduction of e-waste in the planet and the development of medical instruments and implants that the user does not need in a long term, avoiding him the trouble of having another surgical procedure. These devices must be made from biocompatible materials avoiding long-term adverse effects in the environment and the patients.

It is fundamental to develop an analytical model that allows describing the behavior of these materials considering cases in which their porosity may be constant or not, in presence of water or any other biofluid. In order to accomplish this analysis, the reactive diffusion equation is solved based on Bromwich Integral and the Residue Theorem for materials whose porosity is constant, and some of them where their porosity increases linearly or quadratically in terms of its thickness, giving a more general expression. The results show the presence of special functions such as BesselJ, BesselY, LegendreP and LegendreQ. This leads to the analysis of the relation of the electric resistance (per unit length) and the rate of dissolution of the material. These results are utterly important in the design of medical and pharmaceutical nanotechnology where the material's time of dissolution is critical. Furthermore, based on the analytical model, some research lines are suggested in order to achieve future developments in this area.

9118-39, Session 12

A model of the immune-compatibility using the install problem in computer science

Felipe Diaz Jaramillo, Univ. EAFIT (Colombia)

We simulate the immune compatibility using the Install Problem: The idea is to define a Boolean variable for each antibody. This variable is true if the antibody must be in the immune system. The Install Problem refers to the incompatibility that some programs may have with an specific operative system making it impossible to be installed. The analysis was implemented using SMT-solvers, specifically Z3, and the code was wrote using the commands "DependsOn", "Conflict" and "Compatibility_check", making it possible to check the antibody compatibility. The programming languages used to build up the code were Z3-Python and Z3-SMT-Lib. The results can be used in systems biology and in the analysis of immunological therapies. As future line of research it could be developed a more complex algorithm to verify the immunological compatibility.

9118-40, Session 12

Efficiency of nearest neighbor entropy estimators for Bernoulli measures

Alexei Kaltchenko, Wilfrid Laurier Univ. (Canada); Evgeniy A. Timofeev, Yaroslavl State Univ. (Russian Federation)

A problem of nonparametric entropy estimation for discrete stationary ergodic processes is considered. The estimation is based on so-called "nearest-neighbor method".

It is shown that, for Bernoulli measures, the estimator is unbiased, i.e. converges to the (inverse) entropy of the process. Moreover, for symmetric Bernoulli measures, the unbiased estimator can be explicitly constructed by the quadratic optimization of its parameters.

9118-41, Session 12

Improving the efficiency of nonparametric entropy estimation

Alexei Kaltchenko, Wilfrid Laurier Univ. (Canada); Evgeniy A. Timofeev, Yaroslavl State Univ. (Russian Federation)

A problem of improving the efficiency of nonparametric entropy estimation for discrete stationary ergodic processes is considered. The estimation is based on so-called "nearest-neighbor method" and depends on selection of underlying metric on the space of right-sided infinite sequences. Proposed is a new family of metrics which depend on a set of parameters. The estimator is linearly dependent on the parameters, and the best accuracy is achieved by a quadratic optimization of the parameters. It is shown that, under certain conditions, the proposed estimator has a small variance, and the quadratic optimization of the parameters reduces the estimator's bias.

Thursday - Friday 8 –9 May 2014

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9119-1, Session 1

TBD *(Keynote Presentation)*

No Abstract Available

9119-2, Session 2

Probabilistic graphs using coupled random variable

Kenric P. Nelson, Raytheon Co. (United States)

Neural network design has utilized flexible nonlinear processes which can mimic biological systems, but has suffered from a lack of traceability in the resulting network. Graphical probabilistic models ground network design in probabilistic reasoning, but the restrictions reduce the expressive capability of each node making network designs complex. The ability to model coupled random variables using the calculus of nonextensive statistical mechanics provides a neural node design incorporating nonlinear coupling between input states while maintaining the rigor of probabilistic reasoning. A generalization of Bayes rule using the coupled product enables of single node to model correlation between hundreds of random variables. Applying the coupled Bayesian node to the inferencing and classification of UCI's MLR 'Multiple Features Data Set' shows that thousands of linear correlation parameters can be replaced with a single coupling parameter with just a (3%, 4%) reduction in (classification, inference) performance. A coupled bayesian network is demonstrated utilizing a hierarchy of coupled nodes.

9119-3, Session 2

Evaluating data distribution and drift vulnerabilities of machine learning algorithms in secure and adversarial environments

Kevin M. Nelson, BAE Systems (United States); George E. Corbin, Air Force Research Lab. (United States); Christopher W. Banas, BAE Systems (United States); Misty Blowers, Air Force Research Lab. (United States)

Machine learning is continuing to gain popularity due to its ability to solve problems that are difficult to model using conventional computer programming logic. Much of the current and past work has focused on algorithm development, data processing, and optimization. Lately, a subset of research has emerged which explores issues related to security. This research is gaining traction as systems employing these methods are being applied to both secure and adversarial environments. One of machine learning's biggest benefits, its data-driven versus logic-driven approach, is also a weakness if the data on which the models rely are corrupted. Adversaries could maliciously influence systems which address drift and data distribution changes using re-training and online learning. Our work is focused on exploring the resilience of various machine learning algorithms to these data-driven attacks. In this paper, we present our initial findings using Monte Carlo simulations and statistical analysis to explore the maximal achievable shift to a classification model, as well as the required amount of control over the data.

9119-4, Session 3

AHaH computing with thermodynamic RAM

Alex Nugent, M. Alexander Nugent Consulting (United States)

Integrated electronics has approached the atomic wall, where bulk properties give way to discrete,probabilistic and noisy processes. This presents an enormous challenge, as the foundation of modern computing is built on deterministic and fault-free hardware. Our focus on determinism has prevented us from understanding and exploiting one of the most powerful forces in nature: thermodynamic self-organization. At the same time, modern computing architecture based on the separation of memory and processing leads to a well-known problem called the von Neumann bottleneck, a restrictive limit on the data bandwidth between CPU and RAM. We introduce a new approach where memory, processing and intrinsic thermodynamic volatility unite via synaptic plasticity in a simple universal adaptive memory structure we call Thermodynamic Random Access Memory (kT-RAM). We show the application of kT-RAM to problems in machine learning including perception (classification, clustering, feature extraction), planning (combinatorial optimization, prediction) and control (robotic actuation) and introduce the Knowm API, an open-source kT-RAM emulator for application development.

9119-5, Session 3

Energy-efficient STDP-based learning circuits with memristor synapses

Xinyu Wu, Vishal Saxena, Kristy A. Campbell, Boise State Univ. (United States)

It is now accepted that the traditional von Neumann architecture, with processor and memory separation, is ill suited to process parallel data streams which a mammalian brain can efficiently handle. Moreover, researchers now envision computing architectures which enable cognitive processing of massive amounts of data by identifying spatio-temporal relationships in real-time and solving complex pattern recognition problems. Memristor cross-point arrays, integrated with standard CMOS technology, are expected to result in such massively parallel and low-power neuromorphic computing architectures. Recently, significant progress has been made in spiking neural networks (SNN) which expect to emulate data processing in the cortical brain. These architectures comprise of a dense network of neurons and the synapses formed between the neural axons. Further, unsupervised or supervised competitive learning schemes are being investigated by for global training of the network. In contrast to a software implementation, hardware realization of these networks incurs massive circuit overhead for addressing and individually updating network weights. Instead, we employ bio-inspired learning rules such as the spike-dependent timing plasticity (STDP) to efficiently update the network weights. To realize SNNs on a chip, we are densely integrating mixed-signal integrate-and-fire neurons (IFNs) and cross-point arrays of memristors in back-end-of-the-line (BEOL) of CMOS chips. Novel IFN circuits have been designed to drive memristive synapses in parallel while maintaining overall power efficiency (<1 pJ/spike/synapse), even at spike rate greater than 10 MHz. We present circuit design details and simulation results of the IFN with memristor synapses, its response to incoming spike trains and STDP learning characterization.

9119-6, Session 4

Towards leakage resiliency: memristor-based AES design for differential power attack mitigation

Dhireesha Kudithipudi, Rochester Institute of Technology (United States); Ganesh Khedkar, Qualcomm Inc. (United States)

Differential Power Analysis (DPA), are considered as one of the most competent attacks to obtain the secure key of a cryptographic algorithm. Conventional countermeasures for DPAs are focused on hiding and masking techniques at different levels of design abstraction, associated with high power or area cost. However, emerging technologies such as Resistive

Random Access Memory (RRAM), offer unique opportunities to mitigate DPAs with their inherent device characteristics such as variability in write time, reconfigurability, ultra low power (0.1-3 pJ/bit), and high density (4F2). In this research, DPA attacks are mitigated by balancing the memory power profile with custom complementary RRAM modules. AES state memory transaction power traces are balanced when both the RRAM modules are accessed in tandem based on a peripheral low power balancing logic block. Balancing is performed only when the memory is accessed without reducing the overall performance of the system. A baseline RTL architecture for the 128-bit AES cryptoprocessor is designed and implemented in CMOS technology with Hamming weight DPA attack model. DPA attacks mounted on the complementary CMOS and RRAM based AES cryptoprocessor yielded unsuccessful results with no keys recovered, demonstrating the resiliency of the proposed architecture. Moreover, a significant 80% power advantage is achieved with RRAM state memory modules compared to the baseline CMOS.

9119-7, Session 4

Implementation of a synthetic neuron soft processor integrating ion-conducting memristors for advanced computing architectures

Eric Booth, Terry Gafron, Bio Inspired Technologies, LLC (United States)

A configurable neural network based processing platform was designed, simulated and fabricated using the On Semiconductor C5 process with integrated memristor devices from Boise State University. The system is designed using a synthetic neuron fabric (array of memristors) and traditional neural building blocks (synaptic summing junctions using memristors as adjustable weights). The system can be programmed to a specific state using a hardware descriptive language using industry standard interface protocols. It can also adapt to new input through a pulse based training protocol. The initial prototype can learn basic logic functions and recognize simple patterns; however the platform is meant to be scalable to very complex machine learning applications such as environment sensing, threat detection and collision avoidance.

9119-8, Session 4

Heterogeneous CMOS/memristor hardware neural networks for real-time target classification

Cory Merkel, Dhireesha Kudithipudi, Rochester Institute of Technology (United States)

The advent of nanoscale metal-insulator-metal (MIM) structures with memristive properties has given birth to a new generation of hardware neural networks based on CMOS/memristor integration (CMHNNs). The advantage of the CMHNN paradigm compared to a pure CMOS approach lies in the multi-faceted functionality of memristive devices: They can efficiently store neural network configurations (weights and activation function parameters) via non-volatile, quasi-analog resistance states. They also provide high-density interconnects between neurons when integrated into 2-D and 3-D crossbar architectures. Finally, their inherent computation of Ohm's law allows efficient weighing of pre-synaptic neuron activations. However, the infancy of this field has limited exploration of the CMHNN design space, and to date, most published implementations have followed from ad-hoc design methodologies. In this work, we present several neuron,synapse circuits and architectures, and training algorithms for CMHNNs along with their accuracy, area, and power tradeoffs. Then, we present a design methodology based on a neuroevolutionary algorithm to optimize a CMHNN architecture for real-time target classification.

9119-9, Session 5

Hardware-based artificial neural networks for size, weight, and power constrained platforms

Bryant T. Wysocki, Nathan R. McDonald, Clare D. Thiem, Air Force Research Lab. (United States)

A fully parallel, silicon-based artificial neural network (CogniMem CM1K) built on zero instruction set computer technology was used for change detection and object identification in video data. Fundamental pattern recognition capabilities were demonstrated with reduced neuron numbers utilizing only a few, or in some cases one, neuron per category. This simplified approach was used to validate the utility of few neuron networks for use in applications that necessitate severe size, weight, and power restrictions. The limited resource requirements and massively parallel nature of hardware-based artificial neural networks make them superior to many software approaches in resource limited systems, such as micro-UAVs, mobile sensor platforms, and pocket-sized robots.

9119-10, Session 5

A reinforcement learning trained fuzzy neural network controller for maintaining wireless communication connections in multi-robot systems

Xu Zhong, Stony Brook Univ. (United States); Yu Zhou, State Univ. of New York Institute of Technology (United States)

This paper proposes an adaptive multi-robot motion control solution to the fundamental problem of maintaining wireless communication connectivity in a team of collaborative mobile robots, which is of critical importance to reliable functioning of multi-robot systems (MRS) but challenging in physical environments. The performance of MRS relies on efficient inter-robot coordination, which in turn relies on reliable inter-robot communication connections to support efficient data exchange among robots. However, the communication condition among mobile robots in a physical environment is usually unstable due to the signal loss, attenuation, fading and shadowing. In order to maintain reliable communication connections among robots, this paper proposes a decentralized multi-robot motion control strategy which uses a fuzzy neural network (FNN) controller, trained through reinforcement learning, to attain desired wireless communication coverage in a target environment based on perceived wireless link quality among neighboring robots. To keep the structural and computational complexity of the controller reasonable, we design the FNN controller for a robot to maintain the wireless link quality with one neighbor, and, when a robot has multiple neighbors, assign an FNN controller to each neighbor. The FNN controllers for all the neighbors are aggregated for a mobile robot to make decisions on its movement to maintain the desired link quality with its neighbors. The involved controller parameters are trained with reinforcement learning, which, through consecutive interactions with the environment, allows the controller to adapt to the real condition of wireless signal propagation in a physical environment. In the work of this paper, the FNN controller is applied to a multi-robot deployment process to form and maintain desired wireless communication coverage in target environments. The effectiveness of the training and application of the proposed control scheme is verified through simulations, in several environments which are simulated using a probabilistic log-normal signal propagation model with different signal propagation conditions. The proposed control scheme combines the ability of fuzzy inference to adapt to uncertainties in inputs and the ability of artificial neural network to adapt to unknown input-output relationship. It can adaptively guide MRS to form and maintain desired wireless communication coverage under realistic wireless signal propagation conditions in realistic environments.

9119-11, Session 5

A novel pipeline based FPGA implementation of a genetic algorithm

Nonel S. Thirer, Holon Institute of Technology (Israel)

To solve problems when an analytical solution is not available, more and more bio-inspired computation techniques have been applied in the last years.

Thus, an efficient algorithm is the Genetic Algorithm (GA), which imitates the biological evolution process, finding the solution by the mechanism of “natural selection”, where the strong has higher chances to survive. A genetic Algorithm (GA) is an iterative procedure which operates on a population of individuals called “chromosomes” or “possible solutions” (usually represented by a binary code). GA performs several processes with the population individuals to produce a new population, like in the biological evolution.

Thus, the principal phases of the GA are population initialization, fitness calculation (including termination judgment), selection, crossover and mutation.

To provide a high speed solution, pipelined based FPGA hardware implementations are used, with a n- stages pipeline for a n-phases genetic algorithm.

The FPGA pipeline implementations are constraints by the different execution time of each stage and by the FPGA chip resources.

Thus, because the execution time of each GA phase is different, the pipeline must be synchronized according the slowly phase or an asynchronous pipeline, which requires more resources, must be used.

To minimize these difficulties, we propose a bio-inspired technique to modify the crossover step by using “non identical twins”. Thus two of the chosen chromosomes (parents) will build up two new chromosomes (children) not only one as in classical GA.

We analyze the contribution of this method to reduce the execution time in the asynchronous and synchronous pipelines and also the possibility to a cheaper FPGA implementation, by using smaller populations. The full hardware architecture for a FPGA implementation to our target ALTERA development card is presented and analyzed.

9119-12, Session 6

Hardware machine learning for cybersecurity virus detection

Bruce McCormick, CogniMem Technologies, Inc. (United States); Robinson E. Pino, ICF International (United States)

Cybersecurity increasingly is strategic for the protection of financial, personal, corporate, government and infrastructure data assets. Viruses and malware methods and techniques are growing in sophistication and demanding increasingly innovative solutions to detect and prevent cyber attacks. Growth in polymorphic and metamorphic virus approaches demand in situ learning and real time adaptation to address these threats. Machine learning based hardware combines the best ideas from non-linear and fuzzy algorithms powerful enough to address these threats with the performance and power advantages of specialized, but general purpose hardware. This presentation describes applying such neural based hardware trained on network traffic attack data sets and our ongoing research to extend such methods to polymorphic and metamorphic virus detection.

The technology being used is a digital based neural network utilizing Radial Basis Functions (RBF) with Restricted Coulomb Energy (RCE) learning and k Nearest Neighbor (kNN) natively implemented non-linear classifiers. Learning is done on chip at the same performance as recognition. 40,000 hardware based neurons will be used to train on network attack data and code sequences for metamorphic virus detection. The hardware technique is based on a component that accepts vector lengths up to 256 bytes and broadcasts in parallel to 40,000 parallel distance calculating neurons. A fuzzy threshold that is learned is applied to the outputs which are then submitted to a hardware search and sort for the closest result. The device can output the closest match, anomalies detected or data with firing neurons for further statistical analysis. The technology is highly scalable and can be deployed in a heterogeneous facility with traditional approaches at the server or even cost effectively at the client. Techniques for accelerating intrusion detections beyond signature-based algorithms plus handling polymorphic and metamorphic viruses will be described with empirical results.

9119-13, Session 6

The application of top-down abstraction learning using prediction as a supervisory signal to cyber security

Jonathan Mugan, Aram E. Khalili, 21st Century Technologies, Inc. (United States)

Current computer systems are dumb automatons; their blind execution of instructions makes them open to attack. Their inability to reason means they don’t consider the larger, constantly changing context outside their immediate inputs. Their nearsightedness is particularly dangerous because, in our complex systems, it is difficult to prevent all exploitable situations. Additionally, the lack of autonomous oversight of our systems means they are unable to fight through attacks. Keeping our adversaries completely out of our systems may be an unreasonable expectation, and our systems need to adapt to attacks and other disruptions to achieve our objectives. What is needed is an autonomous controller within the computer system that can sense the state of the system and reason about that state. This paper presents SATPAM, which uses prediction to learn abstractions that allow it to recognize the right events at the right level of detail. These abstractions allow SATPAM to break the world into small, relatively independent, pieces that allow employment of existing reasoning methods. In this paper, we present the initial experimental results using SATPAM.

SATPAM goes beyond classification based machine learning and statistical anomaly detection to be able to reason about the system. SATPAM’s knowledge representation and reasoning is more like that of a human. For example, humans intuitively know that the color of a car is not relevant to any mechanical problem, and SATPAM provides a plausible method whereby a machine can acquire such reasoning patterns.

9119-14, Session 6

Index of cyber integrity

Gustave W. Anderson, MacAulay-Brown, Inc. (United States)

[Introduction]

As the saying goes, “You can’t manage what you don’t measure.” This is echoed by the DHS cyber-security roadmap:

“Security metrics are difficult to develop because they typically try to measure the absence of something negative (e.g., lack of any unknown vulnerabilities in systems and lack of adversary capabilities to exploit both known and unknown vulnerabilities). This task is difficult because there are always unknowns in the system and the landscape is dynamic and adversarial. We need better definitions of the environment and attacker models to guide risk-based determination.”

Unfortunately, there is no metric, nor set of metrics, that are both general enough to encompass all possible types of applications and systems yet specific enough to capture the system and attack specifics details. As a result we are left with ad-hoc methods for generating evaluations of the security of our systems. Current state of the art methods for evaluating the security of systems include penetration testing and cyber evaluation tests. For these evaluations, security professionals simulate an attack from malicious outsiders and malicious insiders. These evaluations are very productive and are able to discover potential vulnerabilities resulting from improper system configuration, hardware and software flaws or operational weaknesses.

However, these evaluations are static in the sense that these evaluations cannot provide a holistic view of the applications performance while under attack. Furthermore, beyond providing a measure of adversarial work factor or vulnerabilities before and after assessments, there is a lack of providing definable and repeatable security performance metrics.

Calculating definable and repeatable performance metrics is not a new challenge presented to the research community. Economic and biological indices have provided well defined, meaningful and repeatable measures for some time. Perhaps, the challenge for the security community should be:

How may we leverage the vast research poured into these economic and biological indices in order to develop index of cyber integrity?

Therefore, MacAulay-Brown, Inc. (MacB) presents the index of cyber integrity (ICI), which is modeled after the index of biological integrity (IBI) to provide a holistic measure of the health of a system under test in a cyber-environment.

[Index of Cyber Integrity]

In 1981, Dr. James R. Karr's introduced the index of biological integrity (IBI) and has been widely used to monitor and evaluate the health of complex ecosystems.

"Health, on the other hand, implies a flourishing condition, well-being, vitality, or prosperity. An organism is healthy when it performs all its vital functions normally and properly; a healthy organism is resilient, able to recover from many stresses; a healthy organism requires minimal outside care."

Though Dr. Karr is defining the health of an ecosystem, a healthy cyber system is also resilient, able to recover from many stresses and still capable of normal function in the face of attack.

It is infeasible to model all aspects of a complex ecosystem, not to mention the varied impacts humans have on an ecosystem. The same may be said for cyber systems. Yet, we continually try to develop more sophisticated machine learning techniques to model all aspects of cyber systems with little success. The IBI

provides a broad base measure that integrates site specific metrics to provide an indication of health. In the same way, the ICI provides an index of cyber health through a collection of application and system specific metrics.

9119-15, Session 7

Neuromorphic computing applications for network intrusion detection systems

Robinson E. Pino, ICF International (United States)

No Abstract Available

9119-16, Session 7

An adaptive collective intelligence approach to anomaly detection

James D. Cannady, Nova Southeastern Univ. (United States)

The accurate identification of computer intrusions has been an active area of research for over thirty years, but a computationally efficient approach that can function in a variety of information systems has not been previously developed. Our approach utilizes simple software processes to identify anomalous activity on the protected system that may be indicative of an attack. These neural agents, or Neugents, contain a small number of behaviors that enable them to demonstrate emergent properties and adapt to the unique characteristics of the protected system. The set of behaviors exhibited by each Neugent are limited to data processing and low-level pattern recognition. The individual units quickly build a hierarchical network from a single Neugent that enables the identification of complex activity in a computer environment. Initial experiments have demonstrated that the resulting Neugent network has the ability to identify the components of the local computer environment (OS, applications, etc.) and the "normal" behavior of the system users. These capabilities have enabled the approach to identify unusual activity that is indicative of network-based attacks. By extending the communication between Neugent networks on other networked hosts the network as a whole is able to recognize anomalies that may be indicative of attacks and potential vulnerabilities across the network in a distributive manner. Similar to autonomic processes of biological systems each Neugent network recognizes activity in its local environment and then contributes to the overall situational awareness and security of the entire system.

9119-17, Session 7

A tool for TDM time slot grouping

Christopher P. Kaiser, Clinton E. Park, Michael A. Pittarelli, North Point Defense, Inc. (United States)

We discuss a tool developed to aid in the grouping of time slots into subchannels within a TDM communication channel when the correct grouping is unknown. We approach the task of grouping the time slots as a clustering problem.

The features (compressibility of bit stream, etc.) were selected to minimize slot labelling uncertainty using as training data channels with known layouts. Our fitness function is a weighted ratio of within- to between-subchannel squared error. When the number of subchannels is known, simulated annealing gives faster and more accurate results than a genetic algorithm. Methods for determining the correct number of clusters (gap statistic, etc.) give reasonable results but tend to underestimate the number of subchannels (e.g., all 64 kbit/s CVSD slots in one subchannel). Because of this, a hierarchical agglomerative algorithm is used when the number of subchannels is unknown. The tool provides simultaneous visualization of all time slots as individual bit rasters and the hypothesized slot grouping (at each level of slot merging,

if the agglomerative option is chosen). Open problems include development of a reliable measure of the correct number of subchannels when necessary and improving discrimination of constant and bursting time slots in extremely noisy channels. Individual feature selection was based on conditional entropy of the subchannel label given the feature value; future work will include developing a GA wrapper to select feature weights and parameter values for the parameterized features using as the fitness function partition distance between hypothesized and known channel layouts.

9119-18, Session 7

Machine learning for cyber operations

Misty Blowers, Jonathan Williams, Air Force Research Lab (United States)

Current automatic cyber offensive and defensive capabilities will not remain competitive when they heavily rely on human oversight, a set of pre-defined rules and heuristics, and/or threshold based alerting. An autonomous system is needed which can operate with some degree of self-governance and self-directed behavior. Machine learning can help achieve this goal. Machine learning techniques can help cyber analysts both defensively and offensively. This research will investigate machine learning techniques that are currently being research and are under investigation.

9119-19, Session 7

Bio-inspired diversity for increasing attacker workload

Stephen Kuhn, Thayer School of Engineering at Dartmouth (United States)

Much of the traffic in modern computer networks is conducted between clients and servers, rather than client-to-client. As a result, servers represent

a high-value target for collection and analysis of network traffic. As they reside at a single network location (i.e. IP/MAC address) for long periods of time Servers present a static target for surveillance, and a unique opportunity to observe the network traffic. Although servers present a heightened value for attackers, the security community as a whole has shifted more towards protecting clients in recent years (1). In addition, servers typically remain active on networks for years, potentially decades. This paper builds on previous work that demonstrated a proof of concept based on existing technology. Here we present our clean slate approach to increasing attacker workload through a novel hypervisor and micro-kernel, utilizing next generation virtualization technology to create synthetic diversity of the server's presence.

9119-20, Session 8

Patterns of life in temporal data: indexing and hashing for fast and relevant data retrieval

Georgiy M. Levchuk, Matthew Jacobsen, Mark Weston, Aptima, Inc. (United States)

As temporal datasets grow larger, the need to efficiently and meaningfully search through the data becomes very important. To facilitate this, the need to efficiently and accurately index the data in databases is paramount. This indexing procedure is made especially challenging when the datasets are noisy or incomplete.

Conventional indexing methods require accurate and complete data to work effectively, and are unsuitable for this situation. Current methods to recover lost or corrupted data fail when the amount of lost data is large, as is often the case in temporal data sets. Dimensionality reduction techniques can be used to compress data to fewer attributes in spite of noise, but assume specific distributions of data, rely on the existence of a large number of attributes, and require a non-trivial learning process, which is impossible or impractical in many database environments. To effectively index noisy and incomplete time series data, it is necessary to determine the underlying behaviors used to generate the observed data to begin with.

In this paper, we have developed an indexing procedure to extract the typical latent behaviors occurring within the time series. In particular, we aim to determine the underlying behaviors generating the observations that make up the time series, as these will be the stable in the presence of noise. With these behaviors extracted, the time series can be indexed by the presence or absence of behaviors occurring within.

The method first applies a form of vector quantization to the dataset, which converts the time series into a series of discrete observations. A Hidden Markov Model (HMM) is used to learn the latent states characterizing the time series. The HMM is converted to a unique code which is used to index the time series in a standard relational database.

We compared this indexing method to traditional indexing methods for time series, such as a Fast Fourier Transform (FFT) and Discrete Wavelet Transform (DFT). Our method classified the time series into more meaningful categories than the other methods. In addition, our method was more stable in the presence of varying amounts of noise than the alternatives, achieving over 10-50% improvement in retrieval accuracy and relevance across different data types and noise levels.

9119-22, Session 8

Analysis of large-scale distributed knowledge sources via autonomous cooperative graph mining

Georgiy M. Levchuk, Andres Ortiz, Aptima, Inc. (United States); Xifeng Yan, Univ. of California, Santa Barbara (United States)

Amounts of data that need to be collected, examined and shared during Intelligence, Surveillance, and Reconnaissance (ISR) operations are growing fast due to increasing use of sensors. In order to manage the resulting data deluge, two main technical solutions have recently received significant attention across research and development as well as acquisition programs: Cloud-based distributed processing, and autonomous cooperative data exploitation.

We study a problem of data exploitation in denied areas, where the control of analytical operations and coordination between distributed data access and computing resources, and even existence of these resources, can be disrupted. The Cloud-based technologies are inappropriate for this domain due to weakness of control over computational units and inability to move the data to a central warehouse where it could be indexed, partitioned and analyzed in parallel. Our model provides a solution for autonomous cooperative exploitation of relational data, which is encountered in a variety of applications ranging from geospatial analysis to open source mining.

In this paper, we present a model for processing distributed data across multiple heterogeneous computing resources. Our model exploits the dependencies in the data to provide solution to both distributed querying and pattern learning. In distributed querying mode, the computing resources are assigned the subsets of the query based on high-level information about the data they have access to. This query decomposition is designed to achieve the highest quality of search and optimal balance of computational load between available resources. The resources find local query match estimates and collaborate by exchanging belief messages that efficiently encode how the agents can influence each other's estimates.

In distributed pattern learning mode, the computational resources learn partial correlations between the data they have access to, transfer this knowledge to other agents, and collaboratively learn the patterns across the data they have access to.

Our model achieves better-than-linear computational complexity by using several concepts from probabilistic data analysis and belief propagation. First, we minimize communications among computational resources by only sending the beliefs of high residual values. This reduces the amount of irrelevant messages that have little to no impact on join solution. Second, we use compressive sensing model to reduce the size of communicated messages. Finally, the computational resources use local data prioritization to reduce the computation time of every analysis superstep, resulting in faster production of near-optimal results.

9119-23, Session 8

Trust metrics in information fusion

Erik Blasch, Air Force Research Lab. (United States)

Trust is an important concept for machine intelligence and is not consistent across many applications. In this paper, we seek to understand trust from a variety of factors: sensors, communications, displays, and intelligence processing algorithms. In modeling the various aspects of trust, we provide an example from machine intelligence that supports the various attributes of trust such as sensor accuracy, communication timeliness, machine processing confidence, and display throughput to convey the various attributes that support user acceptance of machine intelligence results. The example used is change detection in motion imagery whereby an analyst needs trust in the identified changes in imagery.

9119-24, Session 9

Quick data evaluation inspired by human vision

Dieter Meinert, ROSEN Technology and Research Ctr. GmbH (Germany)

The environment provides man with a plethora of different stimuli, often only noticed by tiny changes in colour, e.g. different kinds of grass on the ground.

Similarly, in environmental monitoring, small differences are expected in data allowing the discrimination of harmless from dangerous, e.g. discern wind noise from hail, or passing trucks from an earth quake. Unfortunately, often these differences are not detectable immediately in noisy data.

Electronic processing of large amounts of data collected will consume either a large amount of time, or much energy when processing in parallel.

This is not suitable for quick automatic decisions nor useful in nearly autonomous systems with very low energy budget.

Human vision is capable of identifying tiny nuances in colour immediately. Nevertheless, it is based on only three different spectral receptors, each covering rather large areas of the visible spectrum. Each receptor has a specific sensitivity function, partly covering the frequency range of its neighbours.

Perception of colour nuances is performed in the brain through a combination of the intensities collected by these three receptors.

In this paper methods similar to vision are applied to quickly determine the content of signals collected by a monitoring system.

Basically the signal is fed into a set of overlapping filters representing the light receptors, and may be processed by an artificial Neural Network.

It is shown that the system is capable to discern changes in input signals, and to distinguish different signals, even though using only a simple filter-set. It is expected that, by adoption of a more sophisticated filter-set, the system may strongly improve.

9119-25, Session 9

Use of neural computing architecture for radio frequency image and target detection

Daniel Stambovsky, Air Force Research Lab. (United States)

There has been a fair amount of research into the use of bio, particularly neural, inspired computation methods for optical image recognition and processing. The applications of this research both in defense and general use technologies are extremely broad ranging from text recognition to image intelligence equipment identification and classification. The current paper investigates parallel use of neuro-inspired hardware and software on Radio Frequency (RF) reflections for radar-like target and image recognition. In order to test this capability, a RF chirp swept from 21 to 34 GHz was generated by a vector network analyzer and reflected off a metallic plane capable of taking on a variety of shapes. The amplitude measurements of received signals were then formatted and processed by software simulated and hardware based neural networks grounded on systems obtained from CogniMem® Technologies in order to determine if the neuronal computing architecture is capable of learning and identifying specific reflector geometries. While research using neural network computing has been undertaken in the realm of Electronic Intelligence (ELINT) radar emitter identification (Petrov et al.), less effort has been applied to radar data post-processing. Applications of such capabilities would include automated target acquisition and target identification, as well as Synthetic Aperture Radar (SAR) image analysis, target identification and tracking in a noisy environment. Such systems could autonomously analyze radar video data for specific known target types of interest thus requiring less human-in-the-loop system monitoring.

9119-26, Session 9

Intelligent water drops for aerospace and defense applications

Jeremy Straub, The Univ. of North Dakota (United States)

A modified version of the intelligent water drop (IWD) algorithm (originally created by Hosseini) to allow it to be useable for performing planning for air and ground robots based on telemetry provided by orbital craft has been created. The IWD algorithm works by simulating the flow of water drops in a stream-network. The speed of the drops is changed based upon the level of sediment present at each point in the simulated stream. Sediment is collected or dropped based upon the speed of the drop at each point, allowing the network to be dynamically reconfigured at the same time that a planning solution is being searched for.

This paper presents the base IWD algorithm, a simplified version of the algorithm (SIWD) and a derivative of this simplified version that has been adapted and applied to planning air and ground robot paths based upon orbital (for aerial) and aerial (for ground) imagery. An analysis of the performance of the algorithm is presented, which highlights its areas of strength (i.e., generating particular types of solutions) and weaknesses (i.e., lack of repeatability from run to run on the same data) and assesses its viability for use in a variety of persistent surveillance and combat scenarios. A plan for further testing of the algorithm and its applications is presented and discussed.

9119-31, Session 9

Autonomous target tracking of UAVs based on low-power neural network hardware

Wei Yang, Zhanpeng Jin, Binghamton Univ. (United States); Clare Thiem, Bryant Wysocki, Air Force Research Lab. (United States); Dan Shen, Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

Detecting and identifying targets in unmanned aerial vehicle (UAV) images and videos have been a challenging problem due to various types of image distortion. Moreover, the significantly high processing overhead of existing image/video processing techniques and the limited computing resources available on UAVs make most of the processing tasks performed by the ground control station (GCS) in an off-line manner. In order to achieve fast and autonomous target identification on UAVs, it is thus imperative to investigate novel processing paradigms that can fulfill the real-time processing requirements, while fitting to the size, weight, and power (SWaP) constrained environment. In this paper, we present a new autonomous target identification approach on UAVs, leveraging the emerging neuromorphic hardware which is capable of massively parallel pattern recognition processing and demands only a limited level of power consumption. A proof-of-concept prototype is developed based on a micro-UAV platform (Parrot AR Drone) and the CogniMem neural network chip, for processing the video data acquired from UAV camera on the fly. The aim of this study is to demonstrate the feasibility and potential of incorporating emerging neuromorphic hardware into next-generation UAVs and their superior performance and power advantages towards the real-time, autonomous target tracking.

9120-1, Session 1

An enhancement technique for stereoscopic image using salient shape and wavelet transform

Yimin Qiu, Wuhan Univ. of Science and Technology (China); Jinshan Tang, Michigan Technological Univ. (United States)

In the past, stereo vision technology has obtained great development and different stereo video equipment has been developed. One issue in stereo videos is how to enhance the quality of the images for different applications and different viewers. In this paper, we propose a wavelet- transform based approach for enhancing the quality of the original images for stereoscopic systems. The proposed approach exploits wavelet transform to decompose the original image into subbands with different resolutions and image enhancement is performed in the wavelet domain. The image is enhanced by the modification of the high-frequency coefficients. Experimental results show that the proposed approach outperforms conventional approaches.

9120-2, Session 1

Detecting 2-LSB steganography using extended pairs of values analysis

Omed S. Khalind, Benjamin Aziz, Univ. of Portsmouth (United Kingdom)

In this paper we propose an extended pairs of values analysis to detect and estimate the amount of secret messages embedded with 2-LSB replacement in digital images based on chi-square attack and regularity rate in pixel values, as explained in later sections. The method can accurately detect 2-LSB replacement even when the message length is about 10% of the total capacity, it also reaches its best performance with an accuracy of higher than 0.96 and a true positive rate of 0.997 to 0.999 when the amount of data are from 20% to 100% of the total capacity. However, the method puts no assumptions neither on the image nor the secret message, as it tested with a random set of 3000 images from ASIRRA (Animal Species Image Recognition for Restricting Access) public corpus pet images and embedded with a random message for each case. This method of detection could also be used as an automated tool to analyse a bulk of images for hidden contents, which could be useful for digital forensics analysts in their investigation process.

9120-3, Session 1

SS-SVD: spread spectrum data hiding scheme based on singular value decomposition

Victor V. Pomponiu, Univ. of Pittsburgh (United States); Davide Cavagnino, Marco Botta, Univ. degli Studi di Torino (Italy); Harishwaran Hariharan, Univ. of Pittsburgh (United States)

Recently, the Singular Value Decomposition (SVD) received much attention from the watermarking community due to its appealing properties, such as the invariance of singular values (SVs) to common image processing operations and geometric transforms, like rotation, translation and scaling. However, most of watermarking schemes require a lot of prior information to detect the watermark and in addition they are not secure. In this paper we investigate the efficiency of several optimal decoding schemes for the watermark inserted into the SVD domain of the host images using an additive spread spectrum (SS) embedding framework. In order to use the SVs with the SS embedding we adopt several restrictions that ensure that the values of the SVs remain real, positive and sorted. For both the optimal maximum likelihood decoder and sub-optimal decoders we assume that the PDF of SVs can be modeled by the Weibull distribution. Furthermore, we investigate the error probability behavior, i.e., the probability of detection and the probability of false detection, for the applied optimal decoders. By taking into account the efficiency and the necessary auxiliary information for decoding the watermark, we discuss the suitable decoder for various operating situations. Experimental results are carried out to show the imperceptibility and decoding efficiency of the proposed scheme against various attack scenarios.

9120-4, Session 1

Steganography based on pixel intensity value decomposition

Alan A. Abdulla, Harin Sellahewa, Sabah A. Jassim, The Univ. of Buckingham (United Kingdom)

This paper focuses on steganography based on pixel intensity value decomposition. A number of existing schemes such as traditional binary, Fibonacci, Prime, Natural, Lucas, and Catalan are evaluated in terms of payload capacity and stego quality. A new technique based on a specific representation is proposed to decompose pixel intensity values into 16 (virtual) bitplanes suitable for embedding purpose. The proposed decomposition has a desirable property whereby the sum of all bitplanes does not exceed the maximum pixel intensity value, i.e. 255. Experimental results demonstrate that the proposed technique offers an effective compromise between payload capacity and stego quality of existing embedding techniques based on pixel intensity value decomposition. Its capacity is equal to that of binary and Lucas, while it offers a higher capacity than Fibonacci, Prime, Natural, and Catalan when the secret bits are embedded in 1st Least Significant Bit (LSB). When the secret bits are embedded in higher bitplanes from 2nd LSB to 8th Most Significant Bit (MSB), the proposed scheme has more capacity than Natural numbers based embedding. The proposed scheme has less capacity than Fibonacci and Lucas if embedding in higher bitplanes. However, from 6th bitplane onwards, the proposed scheme offers better stego quality. In general, the proposed decomposition scheme has less effect on pixel value when compared to most existing pixel intensity value decomposition techniques when embedding messages in higher bitplanes.

9120-5, Session 1

Taxonomy of LSB steganographic techniques

James C. Collins, Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

The Least Significant Bit (LSB) embedding technique is a well-known and broadly employed method in multimedia steganography, used predominantly in applications involving single bit-plane manipulations in the spatial domain. This paper reviews some of the major techniques of spatial domain LSB steganography, providing the fundamental background of this important embedding method while detailing several of the major evolutionary changes that were driven by increasingly sophisticated LSB steganalysis techniques. Our research focus emphasizes the fact that the LSB technique is not restricted solely to the spatial domain. We establish a much broader view of LSB steganography methods as we summarize and categorize the applications across the full spectrum of carrier domains. Specifically we describe a detailed taxonomy of how many of the LSB embedding techniques are applied in both wavelet and fractal domains, as well as in a number of direct transforms such as the discrete cosine and fast-Fourier transform cases. Finally, we provide a summary of some of the most common LSB embedding techniques implemented in multimedia applications and compare and contrast the robustness of these methods against standard steganalysis attacks.

9120-6, Session 2

Power centroid radar *(Invited Paper)*

Erlan H. Feria, College of Staten Island (United States)

Power centroid radar (PCR) is a fast, powerful and novel technique for adaptive radar. In this paper the nascent PCR methodology is first presented where its derivation is traced to the recent discovery of a dual for information theory which has been called latency theory. The roots of this US patented technique go back to DARPA funded research on adaptive radar of the last decade. The outstanding performance of the technique under severely taxing environmental disturbances will be demonstrated by contrasting its signal to interference plus noise ratio (SINR) performance to significantly more complex schemes such as that derived under the DARPA Knowledge Aided Sensory Signal Processing Expert Reasoning (KASSPER) program. Real-world synthetic aperture radar (SAR) images will be used in this illustration.

9120-7, Session 2

Effectiveness of image features and similarity measures in cluster-based approaches for content-based image retrieval *(Invited Paper)*

Hongbo Du, Harin Sellahewa, The Univ. of Buckingham (United Kingdom)

No Abstract Available

9120-8, Session 2

A mobile system for skin cancer detection and monitoring

Yanliang Gu, Michigan Technological University (United States); Jinshan Tang, Michigan Technological Univ. (United States)

People whose skin is exposed to sunlight for more time are more likely to get skin cancer; and the detection of skin cancer, in its early stage, can save human life. In this PAPER, we will develop an early skin cancer detection and monitoring system using a smart phone. In the system, we will design an iOS app that will be installed in patients' smart phones to collect images of their skin. Images will be sent to a cancer detection system remotely connected to the clients' smart phone. The cancer detection system uses image processing and pattern recognition algorithms to detect, segment, and classify the skin lesions. After the cancer detection system makes a decision on the skin lesions, the system will return the results to the patient's smartphone.

9120-10, Session 2

Automatic identification of early miscarriage based on multiple features quantification from ultrasound images

Shan Khazendar, The Univ. of Buckingham (United Kingdom); Jessica Farren, Imperial College Healthcare NHS Trust (United Kingdom); Hisham Al-Assam, The Univ. of Buckingham (United Kingdom); Ahmed Sayasneh, Imperial College Healthcare NHS Trust (United Kingdom); Hongbo Du, The Univ. of Buckingham (United Kingdom); Tom Bourne, Imperial College Healthcare NHS Trust (United Kingdom); Sabah A. Jassim, The Univ. of Buckingham (United Kingdom)

Ultrasound imaging is considered by gynaecologists to be one of the most powerful techniques for safely visualizing pelvic organs and early pregnancies. Improvements in ultrasound technology have led to a better understanding of early pregnancy development. Such advances have led to earlier and more accurate diagnoses of early pregnancy events. The diagnosis of miscarriage, in particular, has been subject to recent review by the Royal College of Obstetricians and Gynaecologists. It is imperative that there is accurate assessment of the size of early pregnancies to avoid misdiagnosis of a miscarriage and therefore inadvertent termination of pregnancy.

The first sign and measurable element of an early pregnancy is the Gestational Sac (GS). If the gestation sac is above a certain mean diameter (25mm), and a measurable embryonic pole is not seen within it, then a diagnosis of miscarriage can be made. Below this diameter, the pregnancy is classified as a Pregnancy of Unknown Viability (PUV), and a repeat scan for assessment of growth and appearance of an embryo performed at a later date. The assessment of gestational sac size is currently carried out manually. Manual measurements involve multiple subjective decisions, in which dimensions are taken in three planes to establish a Mean Sac Diameter (MSD). This will increase the inter-and intra-observer error.

In this paper an automatic method is proposed for accurate detection of GS in noisy ultrasound images. Furthermore, the proposal extracts the most important geometrical features from GS relevant to miscarriage identification such as Mean Sac Diameter (MSD), volume, perimeter, area, circularity, compactness, solidity, eccentricity. We then used support vector machine (SVM) and K Nearest Neighbour (KNN) classifiers to automatically identify early miscarriage cases. To verify the proposed automated method, we conduct experiments based on stratified cross validation on a data set of 68 ultrasound images captured from two planes - transverse and Sagittal for GS and labelled by domain experts. Our experimental results show that the proposed early miscarriage identification scheme can achieve a high level of accuracy using KNN classifier when the right geometric features are selected.

9120-11, Session 2

A colour and texture based multi-level fusion scheme for ethnicity identification

Hongbo Du, The Univ. of Buckingham (United Kingdom); Sheerko H. M. A. Salah, Koya Univ. (Iraq); Hawkar O. Ahmed, Univ. of the Sulaimani (Iraq)

Ethnicity identification of face images is of interest in many areas of application, but existing methods are few and limited. Different from face recognition of individuals, ethnicity identification classifies faces according to the common features of a specific ethnic group. This paper presents a multi-level fusion scheme for ethnicity identification that combines texture features of local areas of a face using local binary patterns with global color and texture features using HSV binning and wavelet transform. Optimal weightings are assigned to the different features in a similarity measurement for classification. The scheme fuses the decisions from a k-nearest neighbor classifier and a support vector machine classifier into a final decision for identification. We have tested the scheme on a database of face images collected from a number of publicly available databases, and the results demonstrate the effectiveness of the combined facial features and clear improvements on accuracy of identification by the fusion scheme over the identification using individual features as well as other state-of-art techniques.

9120-12, Session 3

Search algorithm complexity modeling with application to image alignment and matching *(Invited Paper)*

Stephen P. DelMarco, BAE Systems (United States)

Search algorithm complexity modeling, in the form of penetration rate

estimation, provides a useful way to estimate search efficiency in application domains which involve searching over a hypothesis space of reference templates or models, as in model-based object recognition, automatic target recognition, and biometric recognition. The penetration rate quantifies the expected portion of the database that must be searched, and is useful for estimating search algorithm computational requirements. In this paper we perform mathematical modeling to derive general equations for penetration rate estimates that are applicable to a wide range of recognition problems. We extend previous penetration rate analyses to use more general probabilistic modeling assumptions. In particular we provide penetration rate equations within the framework of a model-based image alignment application domain in which a prioritized hierarchical grid search is used to rank subspace bins based on matching probability. We derive general equations, and provide special cases based on simplifying assumptions. We show how previously-derived penetration rate equations are special cases of the general formulation. We apply the analysis to model-based logo image alignment in which a hierarchical grid search is used over a geometric misalignment transform hypothesis space. We present numerical results validating the modeling assumptions and derived formulation.

9120-13, Session 3

A novel RANSAC-based Kalman filter algorithm for object characterization and tracking

Sumit Chakravarty, New York Institute of Technology (United States)

Particle Filters has been used extensively in the domain of video based tracking of target objects. They can be viewed as an extension of Kalman Filtering principle. Instead of using object point mass as a tracker as used in the Kalman filter, a number of finite element mass particles are used in particle filter. This is the typical formulation of the Kalman Particle Filter (KPF). Even though this allows the use of non-linearity for state prediction, it is constrained by its choice of the Kalman state transition function. Furthermore the KPF does not provide a methodology of selection of number of the particles and the distribution of the prior. The proper tuning of the above choices is critical for performance of the KPF. This work addresses these constraints of the KPF. It particularly targets two significant areas. Firstly it automates the state matrix generation process by fusing alternate tracking mechanism to the KPF. Secondly and perhaps most significantly it provides a novel technique for selection of number of particles and the prior distribution by use of a procedure similar to the popular RANSAC algorithm. This novel technique is tested for tracking of real video sequence and its efficacy is quantified.

9120-14, Session 3

The iris recognition algorithm under the condition of visible light on portable devices

Siyuan Wang, Yuqing He, Yuan Zeng, Jiaqi Li, Mingqi Liu, Beijing Institute of Technology (China)

With the rapid development of digital and information-based society?the traditional identity authentication can't meet the need of information security, so the method based on biometrics emerges as a new identity authentication. Currently most of the iris recognition algorithm under the condition of visible light can't work smoothly, they mostly call for an infrared illuminator to take images. But we may hardly get an infrared illuminator in our daily life, so it is rare necessary to build a new frame of iris recognition for average person.

In this paper, main object was to deal with the iris images which may contain uneven illumination and interference from scene light?First of all?in the pre-processing part, we adopted an algorithm, which was the adaptive threshold segmentation combine with the gray projection method, to effectively locate the outer edge of the iris area. Then the inside edge of the iris was been located by OTSU adaptive threshold selection algorithm. The next was to normalization the accurate positioned iris circle. And Bilinear interpolation method for interpolation arithmetic was been chosen for a better result. And then the method of histogram equalization was used to enhance the contrast in the unfolded iris image.

According to the position of light spot located before, we put forward the corresponding block coding method, greatly shortened the feature extraction, coding, matching the required time, improve the efficiency of the algorithm.

Finally, we tested our algorithm in the UBIRIS2_1. 20 individuals' iris images was chosen. The result showed that there was an improvement in comparison with other algorithms. As for hamming distance, the average intra hamming distance was been decreased while the inter one increased. These tests proved the proposed algorithm has an encouraging performance.

9120-15, Session 3

Degraded iris image localization and recognition in mobile devices

Yuqing He, Siyuan Wang, Jing Pan, Kun Huang, Jiaqi Li, Beijing Institute of Technology (China)

With the rapid development of digital and information-based society, the traditional identity authentication can't meet the need of mobile information security, so biometrics based authentication is a new identity method?Iris recognition is the most reliable method in biometrics. But most of the iris recognition system should be work in a specific image acquisition module, which always has the near-infrared illumination to get good quality iris texture for the following image analysis and recognition algorithm. When using mobile devices, although we can get the iris images, the iris images was got under natural light. The image quality may degraded and may have nioses caused by the scenary reflection, traditional recognition methods may not work well in this situation. To get better recognition performance, it is necessary to build a new frame of iris preprocessing and recognition under natural light in mobile device.

In this mobile-based iris authentication, the key issue is to deal with the iris images which may contain uneven illumination and interference from scene light. First of all, in the pre-processing procedure, we adopted an coarse to fine algorithm to effectively locate the edge of the iris area. The OTSU dual-threshold segmentation combing with the morphological and gray projection method is used for the pupil's coarse location and the region of the interest (the iris area) extraction, at the same time, the reflection area can also be located. Then an circular integrodifferential operator is used to precisely locate the outer and inner edge of the iris. The next was to normalize the accurate positioned iris circle. Non-concentric model and bilinear interpolation method for interpolation arithmetic was been chosen for a better result. The normalized iris image is enhanced by blocked histogram equalization with transition compensition. According to the position of light spot located before, we put forward the corresponding block coding method. Weighted hamming diatance is used for the feature match. The weighting factor was determined by the reflection location results.

We tested our algorithm in the dataset UBIRIS2_1 and real mobile-based iris images acquired by IPhone. Experimental results showed that the texture and the noises area of the iris can be located efficiently. As for the recognition, the average intra-class hamming distance was been decreased while the inter-class one increased. These results proved the proposed algorithm has an encouraging performance in mobile iris recognition.

Keywords: Iris recognition, mobile device natural light, image localization,

9120-16, Session 3

Long distance face detection and tracking with probabilistic data association

Seokwon Yeom, Daegu Univ. (Korea, Republic of)

Face detection and tracking at a distance has wide applications in security

and surveillance. As multiple frames are often available from CCTV and video camera feeds, acquired information having varying temporal settings can be used to recognize and trace persons of interest over time. In this paper, long-distance face detection and tracking with probabilistic data association is presented. Detection is performed by Adaboost filtering and false alarm reduction methods. Probabilistic data association is utilized to distinguish a human target from falsely detected objects. Kalman filtering is adopted to estimate the state vector of the target. The experiments are performed with outdoor scenes captured at a distance with complicated backgrounds. The preliminary results of real-world images show the efficiency of the proposed algorithm.

9120-17, Session 3

Markov prediction using geometric mixing of weighted count partitions

Richard E. L. Metzler, Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

Online prediction methods estimate likelihood distributions for observation of future symbols by normalizing previously observed symbol counts. During the learning phase, training sequentially updates counts with new observations from the source, and prediction sequentially computes likelihood distributions from the updated count distributions. The theory behind universal prediction tells us that in the limit of many counts, the derived observation frequencies will approach the source probability for stationary, ergodic processes, justifying the usage of direct normalization for likelihood generation. When observations are sparse, however, which is typical at the outset of training, observational frequencies may neither provide sufficient precision for accurate estimation of symbol frequencies nor reflect the nonlocal symbol probabilities of the true source distribution. Smoothing methods compensate for a sparsity of training data with the intention of speeding the convergence rate of derived likelihood distributions to true source distributions. Our work questions the standard approach of additive smoothing and direct count normalization, and in response we propose a novel geometric solution to likelihood generation by mixing likelihoods from smoothed Dirichlet distributions, the method of which is proven optimal for mitigation of a certain loss function. Empirical tests demonstrate that the novel approach converges more quickly than any other methods known to the authors. We also revisit the problems of weighting and fusing a plurality of models into a single, predicted distribution, especially in the Markov sense where higher order memory models are partitions of lower order memory models and propose several schemes that exploit this property for prediction generation.

9120-18, Session 4

Analytic sequential methods for detecting network intrusions

Xinjia Chen, Ernest L. Walker, Southern Univ. and A&M College (United States)

In this paper, we propose an analytic sequential methods for detecting port-scan attackers which routinely perform random ``portscans'' of IP addresses to find vulnerable servers to compromise. In addition to rigorously control the probability of falsely implicating benign remote hosts as malicious, our method performs significantly faster than other current solutions. We have developed explicit formulae for quick determination of the parameters of the new detection algorithm.

9120-19, Session 4

Simultaneous compression and encryption for secure real-time secure transmission of sensitive video transmission

Nazar Al-Hayani, Naseer Al-Jawad, Sabah A. Jassim, The Univ. of Buckingham (United Kingdom)

No Abstract Available

9120-20, Session 4

Develop a solution for protecting and securing enterprise networks from malicious attacks

Harshitha Kamuru, Texas A&M Univ., Kingsville (United States); Mais Nijim, Texas A&M Univ.-Kingsville (United States)

Develop a solution for protecting and securing Enterprise networks from Malicious Attacks :

In the world of computer and network security, there are myriad ways to launch an attack, which, from a network perspective, can generically be defined as "traffic that has malicious intent." There are certainly computer attacks that no firewall can prevent, such as those executed locally on the machine by a malicious user. From the network's perspective, there are numerous types of attack. We can group attacks into two types: brute force and precision. Juniper Firewall has the capability to protect against both types of attack. Denial of Service (DoS) attacks are one of the most well-known network security threats under brute force attacks, which is largely due to the high-profile way in which they can affect networks. Over the years, some of the largest, most respected Internet sites have been effectively taken offline by DoS attacks. A DoS attack typically has a singular focus, namely, to cause the services running on a particular host or network to become unavailable. Some DoS attacks exploit vulnerabilities in an operating system and cause it to crash, such as the infamous Winnuke attack. Others overwhelm a network or device with traffic so that there are no more resources to handle legitimate traffic.Precision attacks often involve a bit more thought than brute force attacks, and typically involve multiple phases, all the way from reconnaissance to machine ownership. Before a precision attack is launched, information about the victim needs to be gathered. This information gathering typically takes the form of various types of scans to determine available hosts, networks, and ports. Ping sweeps are used to determine which hosts are available on a network. Port scans are used to locate available ports on a machine. Screens are configured on a per-zone basis, and they cover a wide variety of attack traffic. Depending on the type of screen being configured, there may be additional settings beyond simply blocking the traffic.Attack prevention is also a native function of any firewall. Juniper Firewall handles traffic on a per-flow basis. We can use flows or sessions as a way to determine whether traffic attempting to traverse the firewall is legitimate. We control the state-checking components resident in Juniper Firewall by configuring "flow" settings. These settings allow you to configure state checking for various conditions on the device. You can use flow settings to protect against TCP hijacking, and to generally ensure that the fire-wall is performing full state processing when desired. We take a case study of attack on a network and perform study of the detection of the malicious packets on a Netscreen Firewall.

In this one i will develop a new solution for securing enterprise networks from malicious attacks .

9120-21, Session 4

Number system for encryption based privacy preserving speaker verification

Lei Xu, Tao Feng, Xi Zhao, Weidong Shi, Univ. of Houston (United

States)

As speech based operation becomes a main hand-free interaction solution between human and mobile devices (i.e., smartphones, Google Glass), privacy preserving speaker verification receives much attention nowadays. Privacy preserving speaker verification can be achieved through many different ways, such as fuzzy vault and encryption. Encryption based solutions are promising as cryptography is based on solid mathematic foundations and the security properties can be easily analyzed in a well established framework. Most current asymmetric encryption schemes work on finite algebraic structures, such as finite group and finite fields. However, the encryption scheme for privacy preserving speaker verification must handle floating-point numbers. This gap must be filled to make the overall scheme practical. In this paper, we propose a number system (NES++) that meets the requirements of both speaker verification and the encryption scheme used in the process. It supports additional homomorphic property of Paillier's encryption, which is crucial for privacy preserving speaker verification. As asymmetric encryption is expensive, we propose a method of packing several numbers into one plain-text and the computation overhead is greatly reduced. To evaluate the performance of this method, we implement Paillier's encryption scheme over NES++ and the packing technique. Our findings show that NES++ can fulfill the gap between speaker verification and encryption scheme very well, and the packing technique improves the overall performance. Furthermore, NES++ is a building block of encryption based privacy preserving speaker verification; the privacy protection and accuracy rate are not affected.

9120-22, Session 4

Image encryption using 2D sine-logistic chaotic map

Zhongyun Hua, Yicong Zhou, Chi-Man Pun, C. L. Philip Chen, Univ. of Macau (Macao, China)

With the properties of unpredictability, ergodicity and initial value/ parameter sensitivity, chaotic maps are good tools in cryptography applications. In this paper, a new two dimensional chaotic map, the 2D Sine-Logistic map is introduced. It can overcome the weaknesses of low dimensional chaotic maps in simple chaotic orbits and high dimensional chaotic maps in expensive computation cost. Its trajectory diagram and Lyapunov exponent distribution are provided to show its good chaotic performance. Using the 2D Sine-Logistic map, a new image encryption algorithm based on the ring shifting is proposed. The ring shifting can change both a pixel's row and column positions at the same time, the shifting order and position are determined by the 2D Sine-Logistic map. Thus, it can separate neighbor pixels very fast, and can achieve a high security level. Simulation results and security analysis show that the proposed image encryption algorithm is with high security level that can resist different kinds of known attacks.

9120-23, Session 5

A new omnidirectional multicamera system for high resolution surveillance

Ömer Cogal, Abdulkadir Akin, Kerem Seyid, Vladan Popovic, Alexandre Schmid, Ecole Polytechnique Fédérale de Lausanne (Switzerland); Beat Ott, Peter Wellig, Armasuisse (Switzerland); Yusuf Leblebici, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

Omni-directional high resolution surveillance has a wide application range in defense and security fields. Early systems used for this purpose are based on parabolic mirror or fisheye lens where distortion due to the nature of the optical elements cannot be avoided. Moreover, in such systems, the image resolution is limited to a single image sensor's image resolution. Recently, the Panoptic camera approach that mimics the eyes of flying insects using multiple imagers has been presented. This approach features a novel solution for constructing a spherically arranged wide FOV plenoptic imaging system where the omni-directional image quality is limited by low-end sensors. In this paper, an overview of current Panoptic camera designs is provided. New results for a very high resolution visible spectrum imaging and recording system inspired from the Panoptic approach are presented. The GigaEye-1 system, with 44 single cameras and 22 FPGAs, is capable of recording omni-directional video in a 360º?100º FOV at 9.5 fps with a resolution over (17,000x5,000) pixels (85MP). Real-time video capturing capability is also verified at 30 fps for a resolution over (9,000x2,400) pixels (22MP). The next generation system with significantly higher resolution and real-time processing capacity, called GigaEye-2, is currently under development. The important capacity of GigaEye-1 opens the door to various post-processing techniques in surveillance domain such as large perimeter object tracking, very-high resolution depth map estimation and high dynamic-range imaging which are beyond standard stitching and panorama generation methods.

9120-24, Session 5

Robust digital image inpainting algorithm in the wireless environment

Gevorg Karapetyan, Hakob G. Sarukhanyan, Institute for Informatics and Automation Problems (Armenia); Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

Image or video inpainting is the process/art of retrieving missing portions of an image without introducing undesirable artifacts that are undetectable by an ordinary observer. An image/video can be damaged due to a variety of factors, such as deterioration due to scratches, laser dazzling effects, wear and tear, dust spots, loss of data when transmitted through a channel, etc. Applications of inpainting include image restoration (removing laser dazzling effects, dust spots, date, text, time, etc.), image synthesis (texture synthesis), completing panoramas, image coding, wireless transmission (recovery of the missing blocks), digital culture protection, image de-noising, fingerprint recognition, and film special effects and production. Most inpainting methods can be classified in two key groups: global and local methods. Global methods are used for generating large image regions from samples while local methods are used for filling in small image gaps. Each method has its own advantages and limitations. For example, the global inpainting methods perform well on textured image retrieval whereas the classical local methods perform poorly. Most of the techniques require a priori knowledge of the locations of the damaged pixels which is unavailable in certain applications. Also, some of the techniques are computationally intensive; exceeding the capabilities of most currently used mobile devices. In general, the inpainting algorithms are not suitable for the wireless environment.

This paper presents a new and efficient scheme that combines the advantages of both local and global methods into a single algorithm. Particularly, it introduces a blind inpainting model to solve the above problems by adaptively selecting support area for the inpainting scheme. The proposed method is applied to various challenging image restoration tasks, including recovering old photos, recovering missing data on real and synthetic images, and recovering the specular reflections in endoscopic images. A number of computer simulations demonstrate the effectiveness of our scheme and also illustrate the main properties and implementation steps of the presented algorithm. Furthermore, the simulation results show that the presented method is among the state-of-the-art and compares favorably against many available methods in the wireless environment. Robustness in the wireless environment with respect to the shape of the manually selected "marked" region is also illustrated. Currently, we are working on the expansion of this work to video and 3-D data.

9120-25, Session 5

Color image attribute and quality measurements

Chen Gao, Karen Panetta, Tufts Univ. (United States); Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

Color image quality measures have been used for many computer vision tasks. In practical applications, the no-reference (NR) measures are desirable because reference images are not always accessible. However, only limited success has been achieved. In this paper, three NR color image attributes, colorfulness, sharpness and contrast, are quantified by new metrics. Using the linear combination of these metrics, a new Color Quality Measure (CQM) is presented. We evaluated the performance of several state of the art no-reference measures for comparison purposes. Experimental results demonstrate the performance of CQM is independent of distortion types, the CQM correlates well with evaluations obtained from human observers, and it operates in real time. The results also show that the presented CQM outperforms previous works with respect to ranking image quality among images containing the same or different contents.

9120-26, Session 5

Implementation of wireless 3D stereo image capture system and synthesizing the depth of region of interest

Woonchul Ham, Chulgyu Song, Hyeokjae Kwon, Luubaatar Badarch, Chonbuk National Univ. (Korea, Republic of)

In this paper, we introduce the mobile embedded system implemented for capturing stereo image based on two CMOS camera module. We use WinCE as an operating system and capture the stereo image by using device driver for CMOS camera interface and Direct Draw API functions. We send the raw captured image data to the host computer by using WiFi wireless communication and then use GPU hardware and CUDA programming for implemetation of real time 3D stereo image by synthesizing the depth of ROI(region of interest). Synthesized stereo image is real time monitored on the shutter glass type 3D LCD monitor. If we have another experimental results conecrning deblurring for near object, in case od endoscope, we added and discuss for deblurring algorithm considering the relative size of aperture of CMOS camera modure compared with the distance of CMOS camera from the object.

9120-27, Session 5

Color image enhancement of low-resolution images captured in extreme lighting conditions

Evan Krieger, Saibabu Arigela, Vijayan K. Asari, Univ. of Dayton (United States)

Security and surveillance videos, due to usage in open environments, are likely subjected to low resolution, low lighting and low resolution, overexposed conditions that are detrimental to the amount of useful details available in the collected images. We propose an approach to improve image quality for low resolution images captured in extreme lighting conditions in order to obtain useful details for various security applications. This technique is composed of a fusion of a nonlinear intensity enhancement process and a single image super resolution process that will provide higher resolution and better visibility. The nonlinear intensity enhancement process consists of dynamic range compression, contrast enhancement, and color restoration processes. The dynamic range compression is performed by a locally tuned inverse sine nonlinear function to provide various nonlinear curves based on neighborhood information. A contrast enhancement technique is used to obtain sufficient contrast and a nonlinear color restoration process is used to restore color from the enhanced intensity image. The single image super resolution process is performed in the phase space and consists of defining neighborhood characteristics of each pixel in order to estimate the interpolated pixels in the high resolution image. The combination of these approaches shows promising experimental results that indicate an improvement in visibility and an increase in usable details. A quantitative evaluation is performed to show an increase in image features, provided by the Harris corner detection and speeded up robust feature detection methods, and improved structural similarity index measures.

9120-29, Session 5

Using DNS amplification DDoS attack for hiding data

Miralem Mehic, VŠB-Technical Univ. of Ostrava (Czech Republic); Miroslav Voznak, Technical Univ of Ostrava (Czech Republic); Jakub Safarik, Pavol Partila, Martin Mikulec, VŠB-Technical Univ. of Ostrava (Czech Republic)

The paper concerns available steganographic techniques that can be used for sending hidden data throw public network. Typically, in steganographic communication it is advised to use popular/often used method for sending hidden data and amount of that data need to be high as much as possible. We confirmed this facts by choosing a Domain Name System (DNS) as a vital protocol of each network and choosing Distributed denial of service (DDoS) attacks that are most popular network attacks currently represented in the world. Apart from characterizing existing steganographic methods we provide new insights by presenting two new techniques. The first one is network steganography solution which exploits free/unused protocols fields and is known for IP, UDP or TCP protocols but has never been applied to DNS (Domain Name Server) which are fundamental part of network communications. The second, explains usage of DNS Amplification DDoS Attack to send seamlessly data throw public network. We changed the standard DNS server to handle the direct command of the coordinating unit and we analyze the detection of these communication. Also we propose the mechanism for confirmation of delivered hidden data throw network. The results of the experiment, that was performed to estimate a total amount of data that can be covertly transferred during these technique, regardless of steganalysis, are also included in this paper.

9120-33, Session 5

Machine learning approach for objective inpainting quality assessment

V. A. Frantc, V. V. Voronin, V. I. Marchuk, A. I. Sherstobitov, Don State Technical Univ. (Russian Federation); S. Agaian, The Univ. of Texas at San Antonio (United States); K. Egiazarian, Tampere Univ. of Technology (Finland)

This paper focuses on a machine learning approach for objective inpainting quality assessment. Inpainting has received a lot of attention in recent years and quality assessment is an important task to evaluate different image reconstruction approaches. Quantitative metrics for successful image inpainting currently do not exist; researchers instead are relying upon qualitative human comparisons in order to evaluate their methodologies and techniques. We present an approach for objective inpainting quality assessment based on natural image statistics and machine learning techniques. Our method is based on observation that when images are properly normalized or transferred to some transform domain, local descriptors can be modeled by some parametric distributions. In this case we use MRF framework to model this local descriptor. The shapes of these distributions are different for non-inpainted and inpainted images. Approach permits to obtain a feature vector strongly correlated with subjective image perception by a human visual system. Next, we use a support vector regression learned on assessed by human images to predict perceived by human quality of inpainted images. We demonstrate how our predicted quality value repeatably correlates with a qualitative opinion in a human observer study.

9120-30, Session Posters-Tuesday

Interactive video audio system: communication server for INDECT portal

Martin Mikulec, VŠB-Technical Univ. of Ostrava (Czech Republic); Miroslav Voznak, Technical Univ of Ostrava (Czech Republic); Jakub

Safarik, Pavol Partila, Jan Rozhon, Miralem Mehic, V?B-Technical Univ. of Ostrava (Czech Republic)

The paper deals with presentation of INDECT project – Intelligent Information System Supporting Observation, Searching and Detection for Security of Citizens in Urban Environment. The INDECT project aims at developing the tools for enhancing the security of citizens and protecting the confidentiality of recorded and stored information. It is a part of the Seventh Framework Programme of European Union. We participate in INDECT portal and the Interactive Video Audio System (IVAS). This IVAS system provides a communication gateway between police officers working in dispatching centre and police officers in terrain. The officers in dispatching centre have capabilities to obtain information about all online police officers in terrain, they can command officers in terrain via text messages, voice or video calls and they are able to manage multimedia files from CCTV cameras or other sources, which can be intersting for officers in terrain. The police officers in terrain are equipped by smartphones or tablets. Besides common communication, they can reach pictures or videos sent by commander in office and they can respond to the command via text or multimedia messages taken by their devices. Our IVAS system is unique because we are developing it according to the special requirements from the Police of the Czech republic. The IVAS communication system is designed to use modern Voice over Internet Protocol (VoIP) services. The whole solution is based on opensource software including linux and android operating systems, Asterisk PBX, Openfire XMPP server or Owncloud clouding system. The technical details of our solution are presented in the paper.

9120-34, Session Posters-Tuesday

Texture descriptor based on local polynomial approximation

A. I. Sherstobitov, V. I. Marchuk, D. V. Timofeev, V. V. Voronin, Don State Technical Univ. (Russian Federation); K. O. Egiazarian, Tampere Univ. of Technology (Finland); Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

No Abstract Available

9120-35, Session Posters-Tuesday

Image extrapolation for photo stitching using nonlocal patch-based inpainting

V. V. Voronin, V. I. Marchuk, A. I. Sherstobitov, E. A. Semenischev, Don State Technical Univ. (Russian Federation); S. Agaian, The Univ. of Texas at San Antonio (United States); K. Egiazarian, Tampere Univ. of Technology (Finland)

Image alignment and mosaicing are usually performed on a set of overlapping images, using features in the area of overlap for seamless stitching. In many cases such images have different size and shape. So we need to crop panoramas or use image extrapolation for them. This paper focuses on novel image inpainting method based on modified exemplar-based technique. The basic idea is to find an example (patch) from an image using local binary patterns, and replacing non-existed ('lost') data with it. We propose to use multiple criteria for a patch similarity search since often in practice existed exemplar-based methods produce unsatisfactory results. The criteria for searching the best matching uses several terms, including Euclidean metric for pixel brightness and Chi-squared histogram matching distance for local binary patterns. A combined use of textural geometric characteristics together with color information allows to get more informative description of the patches. In particular, we show how to apply this strategy for image extrapolation for photo stitching. Several examples considered in this paper show the effectiveness of the proposed approach on several test images.

9121-1, Session 1

MTS in false positive reduction for multi-sensor fusion

Robert Woodley, 21st Century Systems, Inc. (United States)

The Mahalanobis Taguchi System (MTS) is a relatively new tool in the vehicle health maintenance domain, but has some distinct advantages in the current multi-sensor implementations. The use of Mahalanobis Spaces (MS) allows the algorithm to identify characteristics of the sensor signals to identify behaviors in the machines. MTS is extremely powerful with the caveat that the correct variables are selected to form the MS. In this research work, 56 sensors monitor various aspects of the vehicles. Typically, using the MTS process, identification of useful variables is preceded by validation of the measurements scale. However, the MTS approach doesn't directly include any mitigating steps should the measurement scale not be validated. Existing work has performed outlier removal in construction of the MS, which can lead to better validation. In our approach, we modify the outlier removal process with more liberal definitions of outliers to better identify variables' impact prior to identification of useful variables. This subtle change substantially lowered the false positive rate due to the fact that additional variables were retained. Traditional MTS approaches identify useful variables only to the extent they provide usefulness in identifying the positive (abnormal) condition. The impact of removing false negatives is not included. Initial results show our approach can reduce false positive values while still maintaining complete fault identification for this vehicle data set.

9121-2, Session 1

Embedding the results of focused Bayesian fusion into a global context

Jennifer Sander, Michael Heizmann, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Bayesian statistics offers a well-founded and powerful fusion methodology also for the fusion of heterogeneous information sources. However, except in special cases, the needed posterior distribution is not analytically derivable. As consequence, Bayesian fusion may cause unacceptably high computational and storage costs in practice.

Local Bayesian fusion approaches aim at reducing the complexity of the Bayesian fusion methodology significantly. This is done by concentrating the actual Bayesian fusion on the potentially most task relevant parts of the domain of the Properties of Interest. Our research on these approaches is motivated by an analogy to criminal investigations where criminalists pursue clues also only locally.

This publication follows previous publications on a special local Bayesian fusion technique called focussed Bayesian fusion. Here, the calculation of the posterior distribution gets completely restricted to a suitably chosen local context. By this, the global posterior distribution is not completely determined. Strategies for using the results of a focussed Bayesian analysis appropriately are needed.

In this publication, we primarily derive and contrast different ways of embedding the results of focussed Bayesian fusion into a global context. To obtain a unique global posterior distribution, we especially analyze the application of the maximum entropy principle that has been shown to be successfully applicable in measurement technology and in different other areas. To address the special need for making further decisions subsequently to the actual fusion task, we further analyze decision criteria resulting from the application of the theory of linear partial information and principles of lazy decision-making.

9121-3, Session 1

New results in semi-supervised learning using adaptive classifier fusion

Robert S. Lynch, Analytic Information Fusion Systems, LLC (United States)

In typical classification problems the data used to train a model for each class is often correctly labeled, so that fully supervised learning can be utilized. For example, many illustrative labeled data sets can be found at sources such as the UCI Repository for Machine Learning (http://archive.ics.uci.edu/ml/), or at the Keel Data Set Repository (http://www.keel.es). However, increasingly many real world classification problems involve data that contain both labeled and unlabeled samples. In the latter case, the data samples are assumed to be missing all class label information, and when used as training data these samples are considered to be of unknown origin (i.e., to the learning system, actual class membership is completely unknown). Typically, when presented with a classification problem containing both labeled and unlabeled training samples, a technique that is often used is to throw out the unlabeled data. In other words, the unlabeled data are not included with existing labeled data for learning, and which can result in a poorly trained classifier that does not reach its full performance potential. In most cases, the primary reason that unlabeled data are not often used for training is that, and depending on the classifier, the correct optimal model for semi-supervised classification (i.e., a classifier that learns class membership using both labeled and unlabeled samples) can be far too complicated to develop.

In previous work [1], results were shown based on the fusion of binary classifiers to improve performance in multiclass classification problems. In this case, Bayesian methods were used to fuse binary classifier fusion outputs, while selecting the most relevant classifier pairs to improve the overall classifier decision space. Here, this work is extended by developing new algorithms for improving semi-supervised classification performance. Results are demonstrated with real data form the UCI and Keel Repositories.

[1] R. S. Lynch, Jr. and P. K. Willett, "Using classifier fusion to improve the performance of multiclass classification problems," Proceedings of the SPIE Security & Defense Symposium, April 2013.

9121-4, Session 1

Process of probabilistic multisource multi-INT fusion benefit analysis

David J. Wisniewski, Paul C. Hershey, Raytheon Co. (United States)

In order to evaluate the deployment of platforms, sensors, or PED, one must first know the effectiveness or benefit of such an addition to the resulting Intel products. A Process of Probabilistic Multi-Source Multi-INT Fusion Benefit Analysis (PIFBA) has been developed to provide a methodology for statistically computing the probability of detecting, locating, and tracking an object in order to assess current capabilities or the benefit of adding or removing ISR assets in order to obtain the statistically optimal result. While models exist to show the availability of given platforms or sensors, or the effectiveness of using multiple sensors of one type to obtain an answer (e.g. which platforms, sensors, and number of sensors are best to obtain the best location accuracy in a given region at a specified time); no model exists to quantitatively demonstrate the benefits of multi-source multi-INT data fusion. The PIFBA process defines the approach to calculate the probabilistic benefits of integrating or fusing multi-source multi-INT products across a wide range of platforms, sensors, and target objects. This process is designed to be platform, sensor, and Intelligence (INT) agnostic while accepting the specific data INT level parameters to provide a benefit analysis capable of being tailored to specific targets, with specific platforms, sensors, environmental conditions, and timeline scenarios. This process is used to derive results that provide identification of statistical ISR capabilities, their effectiveness, and gaps; as well as, provide analysis of the benefits of applying existing capabilities and new technology or tactics.

9121-5, Session 1

Multisensor fusion with non-optimal decision rules: the challenges of open world sensing

Christian P. Minor, Nova Research, Inc. (United States); Kevin J. Johnson, U.S. Naval Research Lab. (United States)

In this work, simple, generic models of chemical sensing are used to simulate sensor array data and to illustrate the impact on overall system performance that specific design choices impart. The ability of multisensor systems to perform multianalyte detection (i.e., distinguish multiple targets) is explored by examining the distinction between fundamental design-related limitations stemming from mismatching mixture composition and fused sensor measurement spaces, and limitations that arise from measurement uncertainty. Insight on the limits and potential of sensor fusion to robustly address detection tasks in the realistic field conditions can be gained through an examination of a) the underlying geometry of both the composition space of sources one hopes to elucidate and the measurement space a fused sensor system is capable of generating, and b) the informational impact of uncertainty on both of these spaces. For instance, what is the potential impact on sensor fusion in an open world scenario where unknown interferants may contaminate target signals? Under complex and dynamic backgrounds, decision rules may implicitly become non-optimal and adding sensors may increase the amount of conflicting information observed. This suggests that the manner in which a decision rule handles sensor conflict can be critical in leveraging sensor fusion for effective open world sensing, and becomes exponentially more important as more sensors are added. Results and design considerations for handling conflicting evidence in Bayes and Dempster-Shafer fusion frameworks are presented. Bayesian decision theory is used to provide an upper limit on detector performance of simulated sensor systems.

9121-6, Session 2

Data mining to identify out-of-the-box findings in data that cannot be reviewed by a human

Jeremy Straub, The Univ. of North Dakota (United States)

A recent survey of planetary scientists evidenced a concern that the automation of processing of data onboard the spacecraft that cannot (due to communications limitations) be returned to Earth for human review may overlook unexpected patterns in the data that a human may notice. This concern is supported by the numerous historic scientific discoveries that have been stumbled upon when researching a related (or even unrelated topic). As there is no way, short of constraining the spacecraft to minimize its data collection (wasting craft capabilities) to effect the transfer of all collected data to Earth, it is critical to find a method for the identification of these 'out-of-the-box' unexpected findings. This same technology has terrestrial applications for autonomous persistent surveillance and other applications.

This paper proposes the use of data mining onboard a planetary science spacecraft as a technique to solve for this problem. It considers several forms of data mining that could possibly be used and presents an algorithm for identifying unexpected phenomena that may be present in image or topographical data. The extrapolation from these two data types to other prospective types of data is considered. Also considered is the impact of this technology on the acceptance of autonomous data analysis by planetary scientists, based on survey responses.

9121-7, Session 2

Characterization of computer network events through simultaneous feature selection and clustering of intrusion alerts

Siyue Chen, Henry Leung, Univ. of Calgary (Canada); Maxwell Dondo, Defence Research and Development Canada (Canada)

As computer network security threats increase, many organizations implement multiple Network Intrusion Detection Systems (NIDS) to maximize the likelihood of intrusion detection and provide a comprehensive understanding of intrusion activities. However, NIDS trigger a massive number of alerts on a daily basis. This can be overwhelming for computer network security analysts since it is a slow and tedious process to manually analyze each alert produced. Thus, automated and intelligent clustering of alerts is important to reveal the structural correlation of events by grouping alerts with common features. As the nature of computer network attacks, and therefore alerts, is not known in advance, unsupervised alert clustering is a promising approach to achieve this goal. We propose a joint optimization technique for feature selection and clustering to aggregate similar alerts and to reduce the number of alerts that analysts have to handle individually. More precisely, each identified feature is assigned a binary value, which reflects the feature's saliency. This value is treated as a hidden variable and incorporated into a likelihood function for clustering. Since computing the optimal solution of the likelihood function directly is analytically intractable, we use the Expectation Maximization (EM) algorithm to iteratively update the hidden variable and use it to maximize the expected likelihood. Our empirical results, using a labelled Defense Advanced Research Projects Agency (DARPA) 2000 reference dataset, show that the proposed method gives better results than the EM clustering without feature selection in terms of the clustering accuracy.

9121-8, Session 2

Space-based detection of spoofing AIS signals using Doppler frequency

Shanzeng Guo, Defence Research and Development Canada (Canada)

The Automatic Identification System (AIS) is a self-reporting system based on VHF radio to transmit a vessel's identity, position, speed, heading and other parameters to improve maritime domain awareness. However, AIS information can be programmatically spoofed by terrorists or other criminals, who often choose to masquerade as innocent civilians and exploit the vulnerabilities of military and civilian infrastructures for their purposes. Therefore, detecting and localizing a spoofing AIS ship become a critical and challenging issue for maritime security. This paper presents an algorithm to detect and geolocalize a spoofing AIS emitter using space-based AIS signals with its Doppler frequency. With an AIS signal sensor on a fast orbiting satellite, the measured AIS Doppler frequency of an AIS emitter can be used to define a double-napped cone of which the satellite is at its vertex and satellite velocity coincides with its axis, such that the theoretical Doppler frequency derived from the radial velocity to the AIS emitter matches the measured Doppler frequency. All such matches can only lie on either cone extending out from the satellite, which cuts the Earth's surface in two curves, so we know that the AIS emitter must lie somewhere on these curves. Two such AIS Doppler frequency measurements for the same stationary AIS emitter produce two valid curves which intersect at the position of the AIS emitter. Multiple Doppler frequency measurements can be used to better estimate the position fix of an AIS emitter, hence determine the spoofing AIS ship if the estimated position fix unreasonably differs from the position carried in its AIS message. A set of formulas are derived which relate an AIS emitter position to its Doppler frequency measurements.

9121-9, Session 2

A metamaterial-inspired combined inductive-capacitive sensor

Jiang Long, Mitsubishi Electric Research Labs. (United States) and Univ. of California, San Diego (United States); Bingnan Wang, Mitsubishi Electric Research Labs. (United States)

In industrial automation, it is often necessary to detect the proximity of an object and determine if it is metal. Most of proximity sensors have the capability of detecting an object, but are not capable of distinguishing metal from non-metallic objects. This paper proposes a metamaterial-inspired combined inductive-capacitive sensing method for detecting and distinguishing metallic and non-metallic objects, which is realized using a compact sensing structure and detecting circuit.

It is well known that proximity sensing can be realized using capacitive or inductive method. While a single inductive or capacitive sensor cannot distinguish different object, they do have different responses for incoming metallic and non-metallic objects. Thus, it is possible to distinguish objects by combining inductive and capacitive sensing functionalities into a single sensor. To realize the combined functionality, a metamaterial-inspired sensing structure is designed. As a resonant structure, metamaterial presents either capacitive or inductive behavior when operating at off-resonant frequencies. Thus, both inductive and capacitive sensing are simultaneously realized when the sensor is operating at two different frequencies. For demonstration, the proposed sensor is developed from the unit cell of Ω-shape metamaterials. The resonance frequency of the sensor is around 200MHz. The inductive and capacitive sensing is realized at two off-resonant frequencies of 100MHz and 500MHz, respectively. The sensor is fabricated and tested with aluminum and wood pieces. Measurements show distinct results for the two different objects within a range of about 10 mm. Note that the sensing structures can be flexibly designed for different frequency requirements.

9121-10, Session 3

Synchronous radiation sensing and 3D urban mapping for improved source identification

Kevin Kochersberger, Kenneth Kroeger, Gordon Christie, Virginia Polytechnic Institute and State Univ. (United States); Morgan McLean, Remote Sensing Lab. (United States); Wojciech Czaja, Univ. of Maryland, College Park (United States)

The acquisition of synchronous EO imagery and gamma radiation data in aerial overflights of an unmanned aircraft can provide valuable spatial context for radioactive source mapping. Using structure from motion (SfM) methods, a 3D terrain map is generated and classification of the urban terrain is accomplished using reason-based learning methods. This is accomplished by training classifiers on labeled point clouds, where features are computed for each 3D point, or group of points, such as the height from the estimated ground plane, color values for the point, the orientation of the nearest neighbor points, etc. In this case, we are interested in classifiers that will reduce the uncertainty in radiation source position estimation. For instance, vehicles may be likely hiding places for nuclear materials, so a source model with assigned probability is used at the vehicle to reduce the overall uncertainty in position estimation.

Synchronized high resolution EO and low resolution gamma radiation data can be used to find intrinsic correlations between the data sets. Using radioactive material dispersion models or point source models, the derived correlations serve to enhance coarse gamma radiation data. Simulations using injected radiation data show that the method is effective in improving source location estimates with distributed sources at ground level and for point sources that are correlated to 3D structures.

Experiments were flown with an Airstar Mongoose autonomous helicopter carrying an 8" x 2" NaI detector and a two-camera imaging system to provide scaled 3D terrain data. Both quantitative and qualitative results are presented.

9121-11, Session 3

On and efficient and effective intelligent transportation system (ITS) using field and simulation data

Nnanna N. Ekedebe, Wei Yu, Towson Univ. (United States)

Intelligent transportation system (ITS) applications provide a more effective, reliable, and safe driving experience that minimize road traffic congestion. In this paper we compare two vehicular ad hoc network (VANET) routing algorithms namely Dijkstra's shortest path algorithm, and A* algorithm with respect to their effect on total travel time in terms of efficiency, and effectiveness in terms of accuracy of adaptive/dynamic routing from source to destination in a real-world driving scenario using field and simulation data. Our investigation shows that an increase in network size results in scalability problems as the efficiency, and effectiveness of these algorithms diminishes in larger road networks with greater traffic volume densities, flow rates, and congested conditions. In addition, road network state imprecision increases when network size and traffic volume density increases. The ability of these VANET routing algorithms to adaptively route traffic in an efficient an effective manner depends on the type, size, and current roadway conditions.

9121-12, Session 3

Hyperspectral data recovery by incorporating heterogeneous imaging modalities

Alexander Cloninger, Wojciech Czaja, Univ. of Maryland, College Park (United States)

As new imaging modalities arise, the problem of recovery (inpainting) of missing heterogeneous data becomes increasingly important. State of the art techniques for inpainting rely on appropriately designed penalization terms used in certain optimization schemes. These methods range from minimizing total variation, to finding the sparsest solution in a given basis, to minimizing the Ginzburg-Landau energy.

In this paper, we propose a novel approach to inpainting of multispectral and hyperspectral images using prior measurements taken with heterogeneous imaging modalities. We then combine these priors with the aforementioned well studied optimization methods. The priors can take the form of images obtained with different lighting and focus, or under different weather conditions, but also images with spacio-temporal changes, or even all together different remote sensing modalities, such as LiDAR or synthetic aperture radar. Our approach utilizes such manifold learning techniques as diffusion maps or Laplacian eigenmaps that are applied to each image individually, creating new feature spaces, followed by learning a rotation between the feature spaces to place data points from both images in a new joint representation. Next, we apply a novel preimage algorithm to the fused data in conjunction with an inpainting penalization method to recreate the missing pixels. We analyze the role of different inpainting methods used in conjunction with the preimage algorithm, for the purpose of providing an optimal reconstruction of missing information. We also investigate these techniques when no a priori pixel registration exists between the heterogeneous image modalities.

9121-13, Session 3

Tree species identification in a coastal region of Portugal using airborne hyperspectral remote sensing

Prem C. Pandey, Nicholas Tate, Heiko Balzter, Univ. of Leicester (United Kingdom)

Hyperspectral data measure a large number of bands of the electromagnetic spectrum and can be used to demarcate different tree species from each

other. Reflectance spectra were extracted from airborne hyperspectral data for the identification and discrimination of Mediterranean tree species. Airborne hyperspectral AISA Eagle/Hawk sensor imagery was used to carry out this research, having a spectral resolution of 350 nm -2400 nm with 2 m spatial resolution. Spectral signatures were analysed and validated with ground data collected in the field. The field data include the spectral reflectance of leaves measured by a handheld spectroradiometer. Each tree species has its own unique spectral signature. Here, the signatures were used to map Pinus pinea, Pinus pinaster, Eucalyptus globulus, and Juniper species in a coastal region in Portugal. This method is useful for ecosystem conservation and will also help in the timely detection of invasive species in the coastal region. Spatial extent of tree species cover was mapped and validated by ground data. Spectral angle mapper is used to map the study area. This will also mark a step towards coastal environmental protection from invasive species which can be monitored using Hyperspectral remote sensing. Our results show the best wavelength bands for the detection of the different tree species from both the Eagle and Hawk sensors. Best Channels identified to discriminate different tree species are 526-580 nm, 620-650 nm, 800-830 nm, 980- 1050 nm and 1400-1450 nm at visible, NIR and SWIR wavelength ranges. MLC , MDC and SAM classified maps were produced with overall accuracies of 96.38%, 67.5% 50.63% (Kappa coefficient values 0.95, 0.69 0.45)

9121-14, Session 3

Detecting and mapping oil pollution along pipeline routes in tropical ecosystems from multispectral data

Bashir Adamu, Kevin Tansey, Booker Ogutu, Univ. of Leicester (United Kingdom)

The paper is aimed at detecting and mapping oil pollution along pipeline routes in tropical ecosystems from multitemporal Landsat TM and ETM (multispectral) data. The study was conducted in an oil producing environment predominantly mangrove and swamp vegetation in Niger Delta, Nigeria. Ancillary data including oil pipeline map and GPS of spill points were used in selecting sample sites to identify, detect and map the polluted pixels. We identified the polluted pixels by extracting vegetation spectral reflectance and the maps of vegetation indices from the sample sites for a four year period (1986, 1987, 1999 and 2003). The vegetation spectra extracted from the sampled locations indicated high and low reflectance in both the visible and near infrared regions of the wavelength suggesting pollution at the sites with the exception in one location. Similar results were found in the map of vegetation indices with low and high values at polluted and non-polluted pixels respectively from the sample locations for the same period. Supervised neural network classification was optimized using (principal component analysis (PCA) and minimum noise fraction (MNF)) to improve the accuracy of change detection maps. Images (1987, 1999 and 2003) from the post spill events indicated some pixels with low and high vegetation spectral reflectance in both visible and NIR, while the values for vegetation indices improved from -1 to 1 due to successive vegetation regrowth and recovery at the spill sites overtime. To increase acceptability of the results, the ancillary data (oil pipelines and spill points) were overlaid on the vegetation indices and classified maps which correspond to anomalous sites. Further work will be focus on increasing sample size, validation using high resolution imageries and possible assessment of environmental impact of the oil spill at wider buffer zone around the spill sites.

9121-15, Session 4

Enhancing thermal video using a public database of images

Hemin Qadir, Ehsan Ali, Samuel Kozaitis, Florida Institute of Technology (United States)

We added color to fused imagery from a public database for nighttime vehicle operation. We initially fused two spectral bands, thermal and visible, to enhance night vision imagery. Such an approach can give a more detailed image than either of the input scenes; however, the result often has an unnatural color appearance. Therefore, we used a color transfer process to make the nighttime scene appear as if it was viewed in daylight. An effective approach for transferring color has been a look-up table, because they avoid some problems with statistical transformations. However, a single colormap is not sufficient for navigation when the environment is changing. Our approach used a public database of images for navigation. We continuously extracted colormaps from images in the database that were acquired at different locations. Hence, a set of different colormaps was derived for different environments. By comparing image histograms, we were able to select a subband of images and eventually a colormap for the location of interest. We evaluated the results of several comparison metrics and showed the results for several nighttime driving scenarios. We found that our approach could be used in real-time and can aid nighttime vehicle navigation.

9121-16, Session 4

Low-cost, high-performance and efficiency computational photometer design

Sam B. Siewert, Univ. of Alaska Anchorage (United States) and Univ. of Colorado at Boulder (United States); Jeries Shihadeh, Univ. of Colorado at Boulder (United States); Randall Myers, Mentor Graphics, Inc. (United States); Vitaly Ivanov, Univ. of Alaska Anchorage (United States)

Researchers at the University of Alaska Anchorage and University of Colorado Boulder have built a low cost high performance and efficiency drop-in-place computational photometer to test in field applications ranging from port security and safety monitoring to environmental compliance monitoring and surveying. The CP (Computational Photometer) integrates off-the-shelf visible spectrum cameras with near to long wavelength infrared detectors and high resolution digital snapshots in a single device. The proof of concept combines three or more detectors into a single multichannel imaging system that can time correlate read-out, capture, and image processing of all channels concurrently with high performance and energy efficiency. The dual-channel continuous read-out is combined with a third high definition digital snapshot capability and has been designed using and Altera Cyclone-III FPGA (Field Programmable Gate Array) to capture, decimate, down-convert, re-encode, and transform images from two standard definition CCD (Charge Coupled Device) cameras at 30Hz. The continuous standard definition stereo vision can be time correlated to megapixel high definition snapshots. This proof of concept has been laid out for a four-layer PCB (Printed Circuit Board) suitable for use in education and in research for low cost high efficiency field monitoring applications that need multispectral and three dimensional imaging capabilities. Initial testing to be completed in the summer of 2014 in Alaska include field testing in ports, potential test flights in un-manned aerial systems, and future planned missions to image harsh environments in the arctic including volcanic plumes, ice formation, and arctic marine life.

9121-17, Session 4

Forensic prescreening system using coded aperture snapshot spectral imager

Sehoon Lim, David C. Berends, Aveek K. Das, Michael Isnardi, Sek M. Chai, SRI International Sarnoff (United States)

In forensic analysis, the spectral signatures of fluorescent light are used to identify material and classify probative crime samples. In this paper, we present a camera system that enables an instantaneous, non-destructive capture and pre-analysis of the spectral signatures of any and all objects at the crime scene before the lab-based full analysis. Our system detects highly probative samples in the crime scene overwhelmed by the background interference. This spectral classification system is achieved by combining

a coded aperture snapshot spectral imager with a multi-spectral detection algorithm. The spectral datacube is captured and encoded simultaneously into a 2D image using a code aperture, and later decoded by sparsity-based computational framework. An adaptive-cosine estimator (ACE) is used to quantitatively detect and classify the probative samples from the decoded spectral cube. The ACE detection scores the pixel-based spectral responses and the highly scored pixels are segmented as the desired samples by using a spectral library. We present selected results in the 450nm to 600nm range, which is optimally suited for discriminating the luminescence characteristics of the samples.

9121-18, Session 4

True and false symmetries in the classification of optical scatterers

Giovanni F. Crosta, Univ. degli Studi di Milano-Bicocca (Italy); Gorden Videen, U.S. Army Research Lab. (United States)

The TAOS (Two-dimensional Angle-resolved Optical Scattering) is an experimental method by which single airborne aerosols are detected, and then illuminated by a pulsed, monochromatic laser beam. An elliptical mirror collects and images a large portion of the resulting scattering pattern onto a CCD detector. Characterizing and discriminating aerosol classes have applications in the biomedical and security fields.

The interpretation of TAOS data is an inverse problem and fraught with difficulties. This work focuses on the relation between the observed symmetries of TAOS patterns and symmetry operations on the scatterer, such as translation, rotation, reflection, and scaling. In a simplified scalar treatment, the main tools are operator theory and the representation of the scattered wave by the Born sequence. In addition to true symmetries, false ones are shown to arise from detector properties, which are spatially discrete and insensitive to both phase and polarization. Implications on the performance of TAOS pattern analysis are discussed.

9121-19, Session 4

Hybrid fusion and demosaicing algorithm with near-infrared image

Xiaoyan Luo, Jun Zhang, BeiHang Univ. (China); Qionghai Dai, Tsinghua Univ. (China)

Silicon-based digital cameras can record visible and near-infrared (NIR) information. Recently, many researchers capture joint visible/NIR image pair, and then combine them to obtain better quality image. However, the full color visible image must be restored from the color filter array (CFA) samples via demosaicing firstly. Therefore, the image quality in visible/NIR combination can be affected seriously, if some information is lost or some artifacts are generated in the interpolation process. In this paper, we propose a unified framework for visible/NIR image combination and CFA interpolation.

The proposed method aims to reconstruct a high quality image from raw CFA data and the corresponding NIR image, similar to a multi-spectral fusion of color and NIR images. The main advantage of this method lies in the hybrid algorithm with NIR to unify the interpolation and fusion. Our work first analyzes the property of gradient difference between NIR and visible images, and then improves the alternating projections interpolation algorithm according to the correlation of R, G, B channels and gradient difference constraint between visible/NIR images. With such prior information of NIR, the hybrid scheme combines the demosaicing and fusing processes as an optimized algorithm.

The proposed scheme achieves more effective performances for processing the color plane interpolation and the fusion of visible/NIR images simultaneously than treating the interpolation and fusion problems separately not only in image information but also in edge detail. Moreover, the hybrid processing can reduce the computational complexity. We believe that the proposed scheme can be employed to many applications.

9121-20, Session 5

Improving object detection in 2D images using a 3D world model

Herbert Viggh, Peter Cho, Nicholas Armstrong-Crews, Danelle C. Shah, Myra Nam, MIT Lincoln Lab. (United States)

A mobile robot operating in a netcentric environment can utilize offboard resources on the network to improve its local perception. One such offboard resource is a world model built and maintained by other sensor systems. In this paper we present results from research into improving the performance of Deformable Part Model object detection algorithms by using an offboard 3D world model. Experiments were run for detecting both people and cars in 2D photographs taken in an urban environment. After generating candidate object detections, a 3D world model built from airborne LIDAR and aerial photographs was used to filter out false alarm using several types of geometric reasoning. Comparison of the baseline detection performance to the performance after false alarm filtering showed a significant decrease in false alarms for a given probability of detection.

9121-21, Session 5

Fusion of ranging and RGB-D data from robot teams operating in confined areas

Damian M. Lyons, Michael Yu, Fordham Univ. (United States)

We address the problem of fusing laser and RGB-Data from multiple robots operating in close proximity to one another. By having a team of robots working together, a large area can be scanned quickly, or a smaller area scanned in greater detail. However, a key aspect of this problem is the elimination of the spurious readings due to the other robot operating in close proximity. While there is an extensive literature on the mapping and localization aspect of this problem (e.g., Liu and Thrun (2003), Wansiripitak and Murray (2009)), our problem differs from the dynamic map problem in that we look at one kind of transient map feature, other robots, and we know that we wish to completely eliminate the feature.

In prior work, we investigated the problem of fusing laser data from multiple robots in such a manner as to reject the spurious data from other robots. We showed that a combination of local robot-based direction filtering and global map-based visibility filtering at a central map server removed 91% of the spurious data and resulted in a 98% quality improvement.

In this paper we additionally consider the problem of fusing RGB-D data, and we consider two sources for the RGB-D data, Stereovision and Kinect sensors. The additional image component of the data admits new approaches rejecting the spurious readings from other robots. The phenomenon of inattentional blindness (IB) is well know in cognitive psychology as the inability to see an object that might be right in front of the viewer (Friedenberger 2013). We present an approach based on the IB phenomena and compare it with our prior work and with other related work. We show results for these approaches for several experiments for a two robot team operating in a confined indoor environment (4m x 4m).

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9121-22, Session 5

Building animats: neurobiomimetic approach for cognitive systems

Jerome J. Braun, Marianne A. DeAngelus, Kate D. Fischl, Austin R. Hess, Danelle C. Shah, MIT Lincoln Lab. (United States)

Many real-life tasks that are readily accomplished by biological species from humans to rodents prove too challenging for the current state-of-the-art machine-intelligence approaches. Over the past several years, we have been conducting an effort we refer to as 'Cognitive Robotics'. The approaches pursued in this effort are biomimetic, in the sense that they are inspired by and rooted in neuroscience and cognitive science insights. We pursued two complementary directions. The first of these aimed at emulation of cognitive phenomena, including the development of a model of inner-rehearsal cognitive phenomenon. Subsequently, focusing on the second direction which we refer to as 'neurobiomimetic' paradigm, we implemented constructs that constitute rudimentary emulations of biological brains' neural regions and their interactions. Many variants of such constructs are possible, differing in synaptic connectivity specifics, neural region specifics, and other aspects. We refer to these different variants as 'animats'.

In comparison to biological brains, animats are down-scaled for computational feasibility. Nevertheless, they are very large computational constructs, containing many tens of thousands of neurons and many hundreds of thousands synaptic connections in animats implemented in our work. Due to their size and complexity, implementation of neurobiomimetic animats poses an overwhelming developmental challenge. This is exacerbated by the need to experiment with multiple animat structures. The paper discusses the Neurobiomimetic Cognitive Architecture Foundation Framework (NCAFF) we developed to address these challenges. NCAFF separates the animat-development process from the details of the low-level internals. NCAFF allows specifying aspects such as neural regions and synaptic connectivity by its commands, and automatically generates animat constructs according to those commands; algorithmic details underlying those commands at the neuron level are encapsulated within NCAFF. This amounts to complexity-hiding that enables animat implementation and studies to focus on higher-level architectural aspects such as those pertaining to representation of neuroanatomical structures and their connectivity, rather than on the underlying constructional details. This enables animats' implementation and experimentation in a feasible and more reliable manner.

This paper provides an overview of selected aspects of our neurobiomimetic effort, with a particular focus on NCAFF. The computational experiments in this work were in the context of a cognitive task pertinent to autonomous vehicles, namely that of learning an unfamiliar spatial environment and performing navigation by landmarks in that environment. Animat experiments were conducted in a virtual environment which we constructed for that purpose. While results of these experiments we conducted are encouraging, the main value of the work discussed in this paper is not in solving a specific problem of navigation by landmarks. Rather, approaches such as NCAFF enable feasible building of animats which, by emulating aspects of brain structure and processes, may provide a particularly promising path to cognitive systems.

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9121-23, Session 5

Voice and gesture control of a robotic reconnaissance unmanned unit (R2-U2)

Adrian Stoica, Jet Propulsion Lab (United States)

This paper addresses human-oriented command and control technology and an associated natural and effective interface designed to empower the commander of a robotic reconnaissance unmanned unit (R2-U2). The R2-U2 would move in front of an advancing squad, and provide real time Intel of the hostile terrain and threats ahead, generating increased battlefield awareness and highly reducing the risk of surprise for the squad. The tests were performed with a R2-U2 pack of 3 quadrotors. The commander uses a command language (UAV-L) to trigger pre-determined flight behaviors or to take over direct flight maneuvers. He receives the real-time video livestream (pilot view) from the quadrotors' cameras, as well as other situational information (GPS, attitude, position on a map). Over 50 commands voice commands and 20 hand gestures are tested, with a correct classification rate in excess of 97%. Commands were received with commander in the field (relatively quiet setting) or via an internet link, from a remote location, with delays of the order of a second. Group-level of autonomy (GLOA) were tested illustrating the effectiveness of commanding at higher levels of autonomy.

9121-24, Session 6

Integrated multisensor fusion for mapping and localization in outdoor environments for mobile robots

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Autonomous navigation in unstructured outdoor environments still poses great challenges for unmanned mobile systems. As all sensor measurements are influenced by noise, no single sensor is sufficient to reliably allow for precise localization in all situations. Thus multiple sensors have to be used and combined for better robustness and higher precision. In order to avoid involved hardware synchronization of the sensors and incorporate sensors with heterogeneous data rates, the fusion algorithm has to be able to cope with asynchronous sensor data. Furthermore, even in case of time-consuming processing steps, the fusion algorithm has to guarantee real-time operation.

We propose an integrated multi-sensor fusion framework for localization and mapping. The framework is based on extended Kalman filters (EKF) and is capable of combining data from several asynchronous sensors sources. The sensors for localization include an inertial measurement unit, a GPS, a fiber optic gyroscope, and wheel odometry. Additionally a 3D-LIDAR is used for mapping. While the data of the former sensors is fed directly into the EKF, a localization from the measurements of the LIDAR has to be processed in a separate algorithm. This algorithm is performing simultaneous localization and mapping (SLAM). It is building a 3D Normal Distributions Transform map while concurrently estimating a localization in the so far established map with the current scan of the LIDAR. Despite of longer runtime of the SLAM algorithm compared to the EKF update we can still guarantee a high update rate by sophisticatedly joining and synchronizing two parallel EKFs.

9121-25, Session 6

Control fusion for safe multi-robot coordination

Roger V. Bostelman, Jeremy A. Marvel, National Institute of Standards and Technology (United States)

In traditional manufacturing systems, process planning and product scheduling provide only a single sequence of operations to be executed for each product in the manufacturing process. This should be more flexible and new solutions should be approached [1]. Multiple robots used in concert for manufacturing might typically have low-level motion control paired with high-level communication between robots. This was demonstrated in [2] with a self-stabilizing robot supervisory system used to synchronize and schedule the movements of multiple robots. The supervisor receives information from the robot controllers regarding their status, and then, based on the status reports, issues instructions to the devices. While traditional manufacturing systems incorporate this multi-robot control within fixed cells, future smart manufacturing systems will include more complex coordination of mobile manipulators (robot arms mounted on mobile bases). These mobile manipulators are expected to perform tasks such as material handling of variable sub-assemblies and then assembling the parts into larger structures, perhaps side-by-side with humans and in frequently changed locations. The Computing Community Consortium's Robotics Roadmap [3] predicts that in 5 years we will have "inherently safe (hardware and software) professional mobile robots, with manipulation, operating in cooperation with trained humans in all professional environments," including manufacturing.

The National Institute of Standards and Technology (NIST), Performance of Collaborative Robot Systems Project has been researching safety and performance control aspects of multi-robots using a mobile platform (automated guided vehicle, or AGV, with an onboard robot arm). Industrial robot [4] and AGV [5] safety standards mandate failsafe control of these devices with little overlap between standards and thus provide gaps [6] when the two systems are combined into mobile manipulators. One such gap is in competing control decisions based on obstacle detection from the AGV and/or robot arm, as well as other aspects including AGV and robot position and speed. The NIST testbed includes a robot arm and an AGV where each have independent controllers with collaborative decisions to make so that appropriately safe movement proceeds. There are several ways to provide this decision making control, including:

• Independent– each robot makes decisions to account for their own safe control regardless of the other robot;

• Master/Slave – one robot leads decision making for both robots;

• Fused – three alternatives for decision making:

• Shared model (decision rules) – sequential and complimentary state transition;

• Implicit coordination – one robot helps the other to provide appropriate movement; and

• Explicit coordination – one robot negotiates control with the other to provide appropriate movement.

This paper will reference and briefly discuss previously uncovered gaps in AGV and robot standards and detail decision sharing for when robots and AGVs are combined into a collaborative, mobile manipulator system. The NIST mobile manipulator will be tested using independent, master/slave and shared model control with performance measured, analyzed, and results included in this paper. In closing, there will be a plan for testing implicit and explicit coordination control of the mobile manipulator.

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9121-26, Session 6

Camera-laser projector stereo system based anti-collision system for robotic wheelchair users with cognitive impairment

Ashutosh Natraj, Sonia Waharte, Daniel Kroening, Univ. of Oxford (United Kingdom)

This paper presents a system for the real-time estimation of distance to obstacles designed to assist robotic wheelchair users with cognitive impairment. Upon falling under the specified safe distance to an obstacle an alarm alerts that it can be used by the control system to act immediately to avert a possible collision. This system consists of a fish-eye camera, which allows to cover a large field of view (FOV), and a laser circle projector mounted on a fixed baseline. The approach uses the geometrical information obtained by the projection of the laser circle onto the plane simultaneously perceived by the camera. We show a theoretical study of the system in which the camera is modelled as a sphere and show that the estimation of a conic on this sphere allows to obtain the distance between wheel chair and obstacle. We propose some experiments based on simulated data followed by real sequences. The estimated distances from our method are comparable with commercial sensors in terms of its accuracy and correctness. The results from our cheaper system over the expensive commercial sensors prove its suitability for a cheap wheelchair able to assist users with cognitive impairments and that can be functional in dark environments as well.

9121-27, Session 6

A generic multisensor fusions framework for robust odometry in mobile robots

Davide A. Cucci, Matteo Matteucci, Politecnico di Milano (Italy)

Odometry, i.e., the estimate of a mobile robot position and orientation from proprioceptive measurements, is the first milestone in the development of autonomous mobile robots and unmanned vehicles. While the problem is well studied in the literature, and established solutions exist, developers are often required to write their own ad-hoc implementations to adapt such techniques to the particular application or platform considered. In this work we present the ROAMFREE sensor fusion library, a general, open-source framework for pose tracking and sensor parameter self-calibration in mobile robotics. In ROAMFREE, a comprehensive logical sensor library allows to abstract from the actual sensor hardware and processing while preserving model accuracy thanks to a rich set of calibration parameters, such as biases, gains, distortion matrices and geometric placement. The modular formulation of the sensor fusion problem, which is based on state-of-the-art factor graph inference techniques, allows to handle arbitrary number of multi-rate sensors and to adapt to virtually any kind of mobile robot platform, such as Ackerman steering vehicles, quadrotor unmanned aerial vehicles and omni-directional mobile robots. Different solvers are available to target high-rate online pose tracking tasks and offline accurate trajectory smoothing and parameter calibration. High level, clean, C++/Python API, as long as ROS interface nodes, allow to easily fit in existing robot software architectures. After reviewing the structure and the properties of the ROAMFREE sensor fusion library which make it an ideal choice for new, and existing, mobile robot projects, we discuss use cases and real-world validation experiments.

9122-1, Session 1

Automatic theory generation from analyst text files using coherence networks

Steven C. Shaffer, The Pennsylvania State Univ. (United States)

Much of the security analysis knowledge is in textual form. Given the extensive amount of such data, automated processes for effectively analyzing such data are highly sought after. Beyond simple text searches, well-done analysis will involve higher order levels of knowledge, involving what is sometimes referred to as comprehension and analysis in Bloom's taxonomy. It is feasible to generate analysis that reports intelligence at these higher levels, using a combination of natural language processing, coherence theory, and evolution-based algorithms.

Coherence theory sees the concept of meaning as a network of relations, each of which has a relative coherence value. If one imagines a very large network of "everything in the reports", some subnets will have a larger coherence value than others; those with the highest coherence values can be viewed as central themes within the reports. This amounts to searching a large graph for the "best" subgraphs, using the coherence value as an indicator of "best." The notion is fairly intuitive; the problem with this algorithm is that the run time explodes exponentially.

Using an evolution-based algorithm allows for obtaining a sequence of optimal (or quasi-optimal) solutions within a reasonable amount of runtime. Initial experiments have been conducted on soft data for a military situation awareness application using the SYNthetic Counter-INsurgency (SYNCOIN) data set, developed at Penn State. This paper will provide a summary of the prototype algorithms and initial results from processing a subset of the SYNCOIN data.

9122-2, Session 1

Using complex event processing (CEP) and vocal synthesis techniques to improve comprehension of sonified human-centric data

Jeffrey C. Rimland, Mark Ballora, The Pennsylvania State Univ. (United States)

The field of sonification, which uses auditory presentation of data to replace or augment visualization techniques, is gaining popularity and acceptance for analysis of "big data" and for assisting analysts who are unable to utilize traditional visual approaches due to either: 1) visual overload caused by existing displays; 2) concurrent need to perform critical visually intensive tasks (e.g. operating a vehicle or performing a medical procedure); or 3) visual impairment due to either temporary environmental factors (e.g. dense smoke) or biological causes.

Sonification tools typically map data values to sound attributes such as pitch, volume, and localization to enable them to be interpreted via human listening. In more complex problems, the challenge is in creating multi-dimensional sonifications that are both compelling and listenable, and that have enough discrete features that can be modulated in ways that allow meaningful discrimination by a listener.

We propose a solution to this problem that incorporates Complex Event Processing (CEP) with speech synthesis. Some of the more promising sonifications to date use speech synthesis, which is an "instrument" that is amenable to extended listening, and can also provide a great deal of subtle nuance. These vocal nuances, which can represent a nearly limitless number of expressive meanings (via a combination of pitch, inflection, volume, and other acoustic factors), are the basis of our daily communications, and thus have the potential to engage the innate human understanding of these sounds. Additionally, recent advances in CEP have facilitated the extraction of multi-level hierarchies of information, which is necessary to bridge the gap between raw data and this type of vocal synthesis. We therefore propose that CEP-enabled sonifications based on the sound of human utterances could be considered the ultimate in human-centric "big data" compression and transmission.

9122-3, Session 1

A JDL fusion approach to I&W of terrorist attacks

David M. McDaniel, Silver Bullet Solutions, Inc. (United States)

Analytics to support I&W of terrorist attacks, particularly IED attacks, continue to be of critical National importance. In this work we experimented with a novel approach using an analog of the JDL fusion levels and process models of terrorist activities. The operational concept is that analysts hypothesize about of activities that need to be performed to accomplish terrorist attacks to develop process models, similar to what has been done for some time for crime analysis. Data analytics assess the likelihood of these process models based. Analysts may choose to store many different models as search agents for alerting. Models are constructed as extensions within a general ontology to support hierarchal reasoning. The inputs are tokenized utterances which we treat analogously to radar contacts that are associated across the network to conversations about objects in the process models using e.g., Jaccard distance analogously to Mahalanobis distance. Object and event associations (level 2 fusion) are then associated to the terrorist process models, adapting work on process model matching. We setup a Hadoop cluster to hold portions of the Web 1T 5-gram data set to simulate a data collection center. The utterances were generated by randomly dissembling, biasing, and dropping utterances related to the process models. Distributed data fusion MapReduce jobs were then run from a coordinating node, distributing parts of the data fusion problem across the Hadoop nodes.

9122-4, Session 1

Warfighter information services: lessons learned in the intelligence domain

Simon E. Bray, Defence Science and Technology Lab. (United Kingdom)

This paper presents solutions and lessons learned from a concept demonstrator project which implemented the concepts of "Warfighter Information Services" and a "Virtual Knowledge Base" in the intelligence domain, supporting Intelligence Analysts. These concepts were presented in a previous paper which is outlined. Several innovative technologies were employed in the solution, which are presented and their benefits explained. The project was successful, validating many of the design principles for such a system which had been proposed in earlier work. Many of these principles are discussed in detail, explaining lessons learned. The results showed that it is possible to make substantial improvements in the ability to exploit available data, making it discoverable and query-able wherever it is from anywhere within a participating network; and the ability to exploit machine reasoning to make faster and better inferences from available data (fusing data from sensors, databases and natural language text), enabling human analysts to spend more of their time doing more difficult analytical tasks rather than searching for relevant data. It was also demonstrated that a small number of generic Information Processing services can be combined and configured in a variety of ways (without changing any software code) to create "fact-processing" workflows, in this case to create different intelligence analysis capabilities. It is yet to be demonstrated that the same generic services can be reused to create analytical/situational awareness capabilities for logistics, operations, planning or other military functions but this is considered likely.

9122-5, Session 1

A survey of automated methods for sensemaking support

James Llinas, Univ. at Buffalo (United States)

Complex, dynamic problems in general present an analysis environment in which it is difficult to structure reliable a priori procedural knowledge descriptive of the dynamic processes in the environment. Intelligence analysis or military versions of these problems impute added difficulties involving deception of covertness. In turn, these factors create an analysis environment that demands adaptive discovery and learning, or sensemaking, in conjunction with automated toolsets that create helpful but fragmented hypotheses about situational conditions.An analysis requirement therefore exists for the analysts to synthesize these fragmented hypotheses into a complete situational picture or story. This paper describes our efforts to survey and review a number of automated techniques that might be helpful to anaysts in combining such hypotheses into a composite picture. Methods from legal analyses involving evidential analysis, financial analyses involving disparate evidence, and intelligence and military problems are discussed; each of these methods is analyzed in terms of features and benefits, as well as limitations.

9122-6, Session 2

Neural network based visualization of collaborations in a citizen science project

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Citizen science projects are those in which users are asked to collaborate in scientific projects, usually by volunteering idle computer time for distributed data processing efforts or by actively labeling or classifying information -- shapes of galaxies, whale sounds, historical records are all examples of citizen science projects in which users access a data collecting system to label or classify images and sounds.

In order to be successful, a citizen science project must captivate users and keep them interested on the project and on the science behind it, increasing therefore the time the users spend collaborating with the project. Understanding behavior of citizen scientists and their interaction with the data collection systems may help increase the involvement of the users, categorize them accordingly to different parameters, facilitate their collaboration with the systems, design better user interfaces, and allow better planning and deployment of similar projects and systems.

Users behavior can be actively monitored or derived from their interaction with the data collection systems. Records of the interactions can be analyzed using visualization techniques to identify patterns and outliers. In this paper we present some results on the visualization of more than 80 million interactions of almost 150 thousand users with the Galaxy Zoo I citizen science project. Visualization of the attributes extracted from their behaviors was done with a clustering neural network (the Self-Organizing Map) and a selection of icon- and pixel-based techniques. These techniques allows the visual identification of groups of similar behavior in several different ways.

9122-7, Session 2

Visualizing Common Operating Picture of Critical Infrastructure

Lauri Rummukainen, Lauri Oksama, Jussi Timonen, Jouko Vankka, National Defence Univ. (Finland)

This paper presents a solution for visualizing the common operating picture (COP) of the critical infrastructure (CI). The purpose is to improve the situational awareness (SA) of the strategic-level actor and the source system operator in order to support decision making. The information is obtained through the Situational Awareness of Critical Infrastructure and Networks (SACIN) framework. The system consists of an agent-based solution for gathering, storing, and analyzing the information, and a user interface is presented in this paper.

The user interface consists of multiple views visualizing information from the CI in different ways. Different CI actors are categorized in eleven separate sectors and events are used to present meaningful incidents. Current, past, and future states, together with geographical distribution and logical dependencies, are presented to the user. The current state is visualized with a segmented circle to represent event categories. Geographical distribution of assets is displayed with a well-known map tool. Logical dependencies are presented in a simple directed graph and users also have a timeline to review past events.

The objective of the user interface is to provide an easily understandable overview of the status of the CI. Therefore, user testing methods, such as visual walkthrough, informal walkthrough, and the Situation Awareness Global Assessment Technique (SAGAT), were used in the evaluation of the user interface. These sessions improved the overall quality and feasibility of the user interface, enabling the creation of a use case based on real-world data.

9122-8, Session 2

Visualization for multi-INT fusion using JVIEW

Erik Blasch, Alex Aved, James Nagy, Steve Scott, Air Force Research Lab. (United States)

Visualization is important for multi-intelligence fusion and we demonstrate issues for presenting physics-derived (i.e., hard) and human-derived (i.e., soft) fusion results. Physics-derived solutions (e.g., imagery) typically involve sensor measurement that is objective, while human-derived (e.g., text) typically involve language processing. Both results can be geographically displayed for user fusion. Attributes of an effective and efficient display are not well understood, so we demonstrate issues and results for filtering, correlation, and association for users - be they operators or analysts. Operators require near-real time solutions while analysts have the opportunities of non-real time solutions for forensic analysis. In a use case, we demonstrate examples using the JVIEW concept that has been applied to piloting, space situation awareness, and cyber analysis. Using the open-source JVIEW architecture, we showcase a big data solution for multi-intelligence information fusion applications for context-enhanced information fusion.

9122-9, Session 2

A visual analytic framework for sense-making in investigative intelligence

Guoray Cai, The Pennsylvania State Univ. (United States); Geoff A. Gross, Univ. at Buffalo (United States); Dong Chen, The Pennsylvania State Univ. (United States); James Llinas, Univ. at Buffalo (United States)

Intelligence analysis in defense and counter-terrorism has encountered a new level of complexity as data from sensors, human observers, web sources, social media, and various databases need to be synthesized into coherent hypotheses for investigating suspicious activities. This paper focuses on a special type of intelligence analysis, investigative intelligence, which heavily involves the use of human expert knowledge and judgment to perform sense-making activities, develop and synthesize hypotheses about the data, and endeavor to understand emerging threats more thoroughly. Our research was done in coordination with a State of the Art survey of existing methods of automated support to learning/discovery processes that helped in providing a basis for our proposed visual analytic workbench.

Based on a cognitive task analysis of a threat analysis scenario in the counter-insurgency domain, we identified two modes of analytical work: (1) situation monitoring and awareness, and (2) investigative analysis driven by priority intelligence requirements (PIR) received from commanders. We map the processes of the two modes of work roughly to the "information foraging" loop and the "sense-making loop" of Pirolli and Card's Sensemaking theory [1]. In both cases, analysts must mix expert judgment with computational analysis in an opportunistic fashion in order to be productive in dealing with overwhelming amounts of disparate, conflicting, and often deceptive information. We present the design and implementation of a visual analytic workbench that supports investigative analysis. The visual side of our workbench environment implements a linked multiview representation of geospatial, temporal, entity-link networks of the underlying textual reports and observations; this multiview agility is also linked to computational graph-matching and link analysis modules that are able to discover interesting links across entities and events, and interface to the visual system.

[1] P. Pirolli and S.K. Card, The sensemaking process and leverage points for analyst technology. In the Proceedings of the 2005 International Conference on Intelligence Analysis, McLean, Virginia, USA, 2005

9122-10, Session 2

Human terrain exploitation suite: applying visual analytics to open source information to improve tactical human terrain understanding

Timothy P. Hanratty, John Dumer, John T. Richardson, Mark Mittrick, Sue E. Kase, Heather Roy, U.S. Army Research Lab. (United States)

This paper presents the concept development and demonstration of the Human Terrain Exploitation Suite (HTES) under development at the US Army Research Laboratory's Tactical Information Fusion Branch. The HTES is an amalgamation of four complementary visual analytic capabilities that targets the exploitation of open source information. Open source information, specifically news feeds, blogs and other social media, provides unique opportunity to collect and examine salient topics and trends, and provides valuable insights in determining opinions, values, cultural nuances and other sociopolitical aspects within a military area of interest. The early results of the HTES field study indicate that the tools greatly increased the analysts' ability to exploit open source information, but improvement through greater cross-tool integration and correlation of their results is necessary for further advances.

9122-11, Session 3

Profile-based autonomous data feeding: an approach to the information retrieval problem in a high communications latency environment

Jeremy Straub, The Univ. of North Dakota (United States)

A high latency environment, such as a mission to another planet in the solar system (or a craft, like Voyager, beyond the bounds of the solar system), can make data access very frustrating to a user. These environments require several minutes for a command to reach the spacecraft and significant time for the desired data to be returned. This is problematic for creating any type of enjoyable user experience for a typical user and can be frustrating for trained mission scientists and controllers as well. Techniques used in other (non-space) areas hold a possible solution to this problem. User profiling has been shown to be effective at recommending books, movies and other products based on past indications of interest, viewing patterns, a comparison with other users and purchases.

This paper proposes the use of user profiles for the selection and prioritization of data for transmission. This approach has three parts. First, a profile can be created for an individual user and uploaded to the remote craft. This may provide the best results for the particular user; however, it requires transmitting a separate profile up for each prospective user. Second, user correspondence with a set of profiles can be tracked. Finally, this can be extended to match a user not just with a single profile but with (possibly different) profiles for each dimension tracked. The benefits of each of these three approaches are discussed and the pathway to each solutions' implementation is considered.

9122-12, Session 3

Exploiting social media in future army operations: a chemical attack case study

Sue E. Kase, Kirk Ogaard, U.S. Army Research Lab. (United States); Tanvir Al Amin, Tarek Abdelzaher, Univ. of Illinois at Urbana-Champaign (United States)

The prevalence of Social Media (SM) use globally and its growing significance to the evolution of events resulting in social, political, and economic changes has attracted the attention of the Army and other agencies charged with protecting national security interests. SM is a potential source of intelligence as it facilitates information sharing relevant to strategic, operational, and tactical activities. SM could facilitate engagement and shaping endeavors, inform and influence activities, and simultaneously disseminate information and evaluate the effectiveness of the effort. Despite the potential value of SM to the Army, there are significant technological barriers to leveraging its use. Because SM provides real-time information streams, collection and analysis are difficult. Even when collected and analyzed, the veracity of SM information presents a serious problem. SM generated data has the potential to be particularly inaccurate under circumstances when it might be of highest value to the Army, for example, when a crisis evolves in an area of strategic interest where no other means of observation are available. This paper describes experiences with a new fact-finding technology called the Apollo Information Distillation Engine that aims towards mitigating the problem of inaccurate or falsified SM data. Apollo groups data into sets (or claims), corroborating specific observations, then iteratively assesses both claim and source credibility resulting in a ranking of claims by likelihood of occurrence. From a tactical operations perspective, we demonstrate Apollo's fact-finding capabilities in detecting an event of interest and providing situational awareness extracted from SM communications during the Syrian chemical attack.

9122-13, Session 3

A qualitative model for quantifying organizational data-sharing and integration readiness across enterprise warehouses

Mohammed M. Olama, Allen W. McNair, Sreenivas R. Sukumar, James Nutaro, Oak Ridge National Lab. (United States)

In the last three decades, there has been an exponential growth in the area of information technology providing the information processing needs of data-driven businesses in government, science, and private industry in the form of capturing, staging, integrating, conveying, analyzing, and transferring data that will help knowledge workers and decision makers make sound business decisions. Several levels of data integration have been identified across enterprise warehouses: Data access, data storage, harmonized data, data matching, and data grouping. Each level of integration has its own set of complexities that requires a certain amount of time, budget, and resources to implement. Such levels of integration are designed to address the technical challenges inherent in consolidating the disparate data sources. In this paper, we introduce a qualitative model for quantifying an organization and data system's readiness to share data at a given data integration level. It is based largely on the established and accepted framework provided in the Data Management Association (DAMA) International Data Management Body of Knowledge (DMBOK). It comprises several key data management functions and supporting activities, together with several environmental elements that describe and apply to

each function. The developed model provides a pragmatic methodology for evaluating integration risks. It scores the maturity of a system's data governance processes. The higher the computed scores, the better managed the source data system and the greater the likelihood that the data system can be brought in at a higher level of integration.

9122-14, Session 3

Virtual information exchange: enabling secure, dynamic, and policy-controlled interoperation

Geeth de Mel, David Wood, Seraphin Calo, Keith Grueneberg, IBM Thomas J. Watson Research Ctr. (United States); David Braines, IBM United Kingdom Ltd. (United Kingdom); Paul Sullivan, Intelpoint Inc. (United States); Tien Pham, U.S. Army Research Lab. (United States); Dinesh Verma, IBM Thomas J. Watson Research Ctr. (United States)

The Virtual Information Exchange (VIE) strives to enable coalition service providers to share services and interoperate with other shared services in a controlled and secure environment. Services may dynamically and selectively be made available from behind a VIE gateway which then exposes those services to other gateways participating in the coalition according to policy constraints. Services are then only accessible across gateways in a secure, controlled and monitored fashion. Services are registered with semantic meta-data to enable matchmaking between service consumers and providers. Further, services can be composed and recomposed using a service template that describes the services it requires. VIE supports a role-based onetime authentication so that effective policy constraints could be placed at service level and leverage those whilst selecting services to instantiate service templates. The gateways form an overlay network to create a distributed registry of services that can accommodate dynamic changes to the network topology. Further, the VIE provides a generic framework that can be easily configured to support different domains, including the mobile ad hoc coalition scenarios we envision. We will describe the details of the proposed architecture, use case scenarios and some early experience with the VIE.

9122-16, Session 3

Utilizing semantic wiki technology for intelligence analysis at the tactical edge

Eric G. Little, Modus Operandi, Inc. (United States)

Challenges exist for intelligence analysts to efficiently and accurately process large amounts of data collected from a myriad of available data sources. These challenges are even more evident for analysts who must operate within small military units at the tactical edge. In such environments, decisions must be made quickly without guaranteed access to the kinds of large-scale data sources available to analysts working at intelligence agencies. Improved technologies must be provided to analysts at the tactical edge to make informed, reliable decisions, since this is often a critical collection point for important intelligence data. To aid tactical edge users, new types of intelligent, automated technology interfaces are required to allow them to rapidly explore information associated with the intersection of hard and soft data fusion, such as multi-INT signals, semantic models, social network data, and natural language processing of text. Abilities to fuse these types of data is paramount to providing decision superiority. For these types of applications, we have developed BLADE. BLADE allows users to dynamically add and delete data via a semantic wiki, allowing for improved interaction between different users. Analysts can see information updates in near-real-time due to a common underlying set of semantic models that allows for updates on related data points from independent users tracking different items (persons, events, locations, organizations, etc.). The wiki can capture pictures, videos and related information. New information added directly to pages is automatically updated in the semantic model making that data integrated with other users' pages.

9122-17, Session 4

User-centric incentive design for participatory mobile phone sensing

Wei Gao, Haoyang Lu, The Univ. of Tennessee Knoxville (United States)

Mobile phone sensing applications rely on participation of individual smartphone users. Participating users transmit their sensed data via 3G or WiFi communications to a sensing server residing in the remote cloud, in which the sensed data is accumulated, processed, and published. Most designs of mobile phone sensing assume voluntary user participation which is unrealistic in practice. A straightforward solution to user incentive design is to offer payments that compensate users' sensing costs, but does not prioritize the benefits of participating users.

In this paper, we propose a user-centric incentive design for participatory sensing systems. Our basic idea is to enable a user to express her generic tolerance to sensing costs by flexibly adjusting her preferred Level of Participation in Sensing (LoPS) at runtime, and further to exploit reduction of sensing costs with respect to a user's LoPS as the user's incentive. The key insight behind this counter-intuitive design is the selfish but rational nature of human beings. A user's willingness to participate in sensing is negatively proportional to her sensing costs, and a user consents to participate in a sensing task which is cost-free even if no incentive is provided at all.

We realize our design by proposing a universal sensing platform that is integrated to the smartphones' Operating Systems. This platform provides techniques to generically quantify the requirements of sensing performance specified by heterogeneous sensing tasks, and further customizes a task-independent sensing plan at runtime according to the user's LoPS and system resource conditions. This generic sensing plan is then taken as input for reducing the sensing costs in various aspects, while satisfying the requirements of sensing performance.

9122-18, Session 4

Conversational sensing

Alun D. Preece, Christopher Gwilliams, Christos Parizas, Diego Pizzocaro, Cardiff Univ. (United Kingdom); David Braines, IBM United Kingdom Ltd. (United Kingdom)

Recent developments in sensing technologies, mobile devices, and context-aware user interfaces have made it possible to represent information fusion and situational awareness for Intelligence, Surveillance, and Reconnaissance (ISR) activities as a conversational process among actors at or near the tactical edges of a network. Motivated by use cases in the domains of coalition operations and Company Intelligence Support Team (COIST) tasks, we present an approach to information collection, fusion, and sense-making based on the use of natural language (NL) and controlled natural language (CNL) to support richer forms of human-machine interaction. The approach uses a conversational protocol to facilitate a flow of messages from NL to CNL and back again in support of interactions such as: turning eyewitness reports from human observers into actionable information (from both soldier and civilian sources); fusing information from humans and physical sensors (with associated quality metadata); and assisting human analysts to make the best use of available sensing assets in an area of interest (governed by management and security policies). We highlight the use of CNL as a common formal knowledge representation for both machine and human agents to support reasoning, semantic information fusion, and generation of rationale for inferences, in ways that remain transparent to human users. We include preliminary results of experiments with human subjects, exploring the utility of the CNL representation and various alternative styles for user feedback, including NL, CNL, and graphical feedback.

9122-19, Session 4

Technology and the analyst: using ACT-R models to understand collective sensemaking and the role of technology in mediating cognition

Darren P. Richardson, Paul R. Smart, Univ. of Southampton (United Kingdom); Katia Sycara, Carnegie Mellon Univ. (United States)

The next generation of analysts will have an array of new and powerful tools at their disposal. However, despite the rapidly evolving technology, the humans that form the core of the analysis-based activities will remain largely unchanged. It follows that the technology will have to be designed to suit their cognitive characteristics and limitations. Additionally, where such analysts are working in groups, issues concerning social interaction and communication have to be taken into account. In view of these facts, there is a compelling need to advance our understanding regarding the interaction between cognitive, social and technological factors in collective problem-solving situations.

This paper proposes a computational model that can be used to perform experimental studies into collective sensemaking. The model consists of multiple instances of the ACT-R cognitive architecture, which is a neurobiologically-inspired computational model of human cognition. ACT-R has been used to model cognitive performance in a broad variety of task contexts; however, for the most part, its use has tended to focus on the performance of individual subjects rather than groups of interacting individuals. By using multiple ACT-R agents that are able to communicate with one another, we are able to perform cognitive social simulations into collective sensemaking. In particular, we can explore the interplay between cognitive, social, informational and technological factors and the role they play in collective sensemaking performance within a dynamic information landscape. We describe an experiment using this system and present some preliminary results.

9122-21, Session 4

Language and dialect identification in social media analysis

Stephen Tratz, Douglas Briesch, Jamal Laoudi, Clare Voss, Melissa Holland, U.S. Army Research Lab. (United States)

Historically unwritten Arabic dialects are increasingly appearing online in social media texts and are often intermixed with other languages, including Modern Standard Arabic, English, and French. The next generation analyst will need new capabilities to quickly distinguish between the languages used in a given text and to identify informative patterns of language switching that occur within a user's social network – patterns that may correspond to socio-cultural aspects such as participants' perceived and projected group identity. This paper presents work to (i) collect texts written in Moroccan Darija, a low-resource Arabic dialect from North Africa, and (ii) build an annotation tool that (iii) supports development of automatic language and dialect identification and (iv) provides social and information network visualizations of languages identified in tweet conversations.

9122-22, Session Posters-Tuesday

Application of the JDL data fusion process model for the condition monitoring of aircraft

Joseph T. Bernardo, The Pennsylvania State Univ. (United States)

Information fusion has been proposed as a way to enhance the diagnostic capability of condition-based maintenance technologies. However, there is a limited understanding of where the entire information fusion process could and should be applied in the condition monitoring of aircraft. Condition-based maintenance (CBM) refers to the philosophy of performing maintenance when the need arises, based upon indicators of deterioration in the condition of the machinery. Traditionally, CBM involves equipping machinery with electronic sensors that continuously monitor components and collect data for analysis. The addition of the multisensory capability of human cognitive functions (i.e., sense-making, problem detection, planning, adaptation, coordination, naturalistic decision making) to traditional CBM may create a fuller picture of machinery condition. Future progress in information fusion will be made by increasing the understanding of a variety of information fusion processes and applying them to the condition-based maintenance applications domain for aircraft. This research explores the underlying processes identified in the Joint Directors of Laboratories (JDL) Data Fusion Process Model and describes their use in the condition monitoring of aircraft.

9122-23, Session Posters-Tuesday

Predicting student success using analytics in course learning management systems

Mohammed M. Olama, Gautam Thakur, Allen W. McNair, Sreenivas R. Sukumar, Oak Ridge National Lab. (United States)

Predicting college student performance is crucial for both the student and educational institutions. It can support timely intervention to prevent students from failing a course and also to provide additional services. In this paper, we present our efforts in conducting predictive analytics to academic data available in the Learning Management System such as Moodle. We first identified the data features useful for predicting student outcomes such as students' scores in homework assignments, quizzes, exams, and their activities in discussion forums, in addition to their total GPA (at the same term they enrolled in the course). Then, Logistic Regression and Neural Network predictive models are used to identify students as early as possible that are in danger of failing the course they are currently enrolled in. These models compute the likelihood of any given student failing (or passing) the current course. The outcome is to prioritize students for intervention and referral to academic advisors. Numerical results will be presented to evaluate and compare the performance of the developed models and their predictive accuracy.

9123-1, Session 1

Superdense teleportation for space applications

Trent M. Graham, Univ. of Illinois at Urbana-Champaign (United States); Herbert J. Bernstein, Hampshire College (United States); Hamid Javadi, Jet Propulsion Lab. (United States); Barry J. Geldzahler, NASA Headquarters (United States); Paul Kwiat, Univ. of Illinois at Urbana-Champaign (United States)

The transfer of quantum information over long distances has long been a goal of quantum information science. Loss and random fluctuations are particularly devastating to quantum communication channels, as quantum states cannot be amplified and error correction protocols are presently very difficult to implement. These limitations make communication of quantum states to distant objects a difficult prospect and have thus far limited quantum communication protocols to terrestrial applications. However, by encoding quantum states in degrees of freedom that are resistant to atmospheric turbulence our experiment might be adapted to earth-to-space communication. We are currently designing and implementing an entanglement-assisted quantum state communication protocol which can be adapted for deployment on the International Space Station (ISS). Specifically, we are developing an experimental protocol known as superdense teleportation (SDT) to communicate, using only a classical communication channel, a quantum state jointly encoded in polarization and temporal mode of a photon between two remote parties that share an entangled photon pair. SDT has reduced classical information cost per state parameter and simplified measurements compared with traditional entanglement-assisted quantum communication techniques such as quantum teleportation and remote state preparation. Leveraging from the results of our prototype experiment and other satellite and ISS laser communication research, we will work toward flight validation of SDT for the ISS, as a prelude to eventual near-earth and deep-space quantum communication. We will also discuss current experimental results using SDT to communicate polarization and spatial-mode quantum states between remote parties.

9123-2, Session 1

Quantum state regeneration in entanglement based QKD

Reinhard Erdmann, Advanced Automation Corp. (United States); David H. Hughes, Richard J. Michalak, John Malowicki, Paul Cook, Air Force Research Lab. (United States)

The first Quantum Key Distribution (QKD) protocols were based on the principle of 'single photon states on demand;' the interception (and regenerated replacement) of an indivisible photon reveals its presence by reconciliation errors induced between intended users. Later QKD protocols used entangled photon pairs, where eavesdropping is also revealed by the induced errors. In both cases it is measurements performed in unknown bases, which induce errors. Even for random selection of bases, intended users can reconcile the matched choices to construct a secret shared key, but an eavesdropper cannot. It is generally assumed that variation of measurement bases is fundamental to operational QKD. It is shown here that it is not, and that under certain conditions secure QKD can be implemented without any variation of bases. An explicit example is provided by time-gated detection, based on the inherent time delay induced by any eavesdropper in measuring-regenerating a photon state. In a free-space QKD application, relativity constrains signal propagation velocity such that it is not possible for any regenerated photon to enter the gated time slot established by the users. Any photon that does enter the proper time slot is either the entangled partner, or an incorrect substitute (which induces Bell Inequality violations established in Ekert protocols). The significant difference is that no basis settings require variation, thereby demonstrating that what is fundamental to entangled state QKD is the inability by an Eavesdropper to deliver a properly regenerated photon. This has application significance in time-gated hyper-entangled QKD; the magnified difficulties for any potential eavesdropper are analyzed.

9123-3, Session 1

LDPC error correction for Gb/s QKD

Alan Mink, Anastase Nakassis, National Institute of Standards and Technology (United States)

Low Density Parity Check (LDPC) error correction is a one-way algorithm that has become popular for quantum key distribution (QKD) post-processing. As researchers delve into Gb/s QKD key production rates, attached processors have become a necessity. Initially FPGAs were the preferred attached platform used to provide real-time and high speed processing. FPGAs have been instrumental in achieving Mb/s QKD key production rates. But FPGAs can't scale LDPC algorithms to Gb/s performance. FPGAs lack sufficient amounts of memory, a critical resource for LDPC algorithms, and the bulk of that memory is not n-ported which is required for highly parallel implementations. Graphic processing units (GPUs) are alternative platforms that provide parallelism through many processing elements and multiple GPUs can be supported by one computer. Although GPUs have large global memories that can support many parallel LDPC datasets, they have limited fast local memories that limit the size of a dataset. While privacy amplification dictates large datasets, about a Mbit or more, error correction can be conducted on smaller datasets and the accumulated results of multiple datasets combined into a larger one needed for privacy amplification. LDPC performance of 100 Mb/s has been reported on a GPU. Such performance requires use of GPU instructions and GPU streaming. We present the details of our various LDPC GPU implementations and the performance that each achieves. A 100 Mb/s LDPC GPU performance implies 10 GPUs to attain 1 Gb/s. The new generation of GPUs is advertised as an order of magnitude faster, implying one GPU (or 2) could achieve Gb/s performance.

9123-4, Session 1

Polar codes in a QKD environment

Anastase Nakassis, Alan Mink, National Institute of Standards and Technology (United States)

The paper addresses the practical issues of adapting Polar code error correction to the quantum key distribution (QKD) protocol. We also discuss our approach to designing efficient Polar codes and present the error correction performance results of those codes. We also present the detail of various Polar code implementations and how concern over number precision infulences those implementations. detail and of Polar code adaptations that fit the requirements of the QKD model and addresses the practical issues in the development of efficient decoding procedures.

9123-5, Session 1

Spectral-temporal-polarization encoding of photons for multi-user secure quantum communication.

Eric Donkor, Univ. of Connecticut (United States)

We describe a Quantum Key Distribution protocol that combines temporal-, spectral- and polarization-encoding of photons for secure communication over an interconnected network of users. Temporal encoding is used to identify a user's location or address on the network. Polarization encoding is used to generate private cryptographic key. Polarization encoded information is locally and randomly generated by users and exchanged only over a dedicated secure channel. Spectral encoding allows for the detection

of eavesdropping and tampering by a malicious agent. Temporal-spectral signals sent from the network administrator (Alice) to a user are bright light source. On the other hand spectral-temporal signal from a network user (Bob) to the administrator (Alice) are single photons. Signals are sent across the network as ordered light pairs. The ordering format is randomly chosen and are revealed only at the time of key selection between the parties so that a secure one-time cryptographic pad can be generated.

9123-6, Session 2

Adaptive multicarrier quadrature division modulation for continuous-variable quantum key distribution

Laszlo Gyongyosi, Budapest Univ. of Technology and Economics (Hungary) and Hungarian Academy of Sciences (Hungary); Sandor Imre, Budapest Univ. of Technology and Economics (Hungary)

In a continuous-variable quantum key distribution (CVQKD) system, the information is conveyed by coherent state carriers. The quantum continuous variables are sent through a quantum channel, where the presence of the eavesdropper adds a white Gaussian noise to the transmission. The amount of tolerable noise and loss is a crucial point in CVQKD, since it determines the overall performance of the protocol, including the secure key rates and transmission distances. In this work, we propose the adaptive multicarrier quadrature division (AMQD) modulation technique for CVQKD. The method granulates the Gaussian random input into Gaussian subcarrier continuous variables in the encoding phase, which are then decoded by a continuous unitary transformation. The subcarrier coherent variables formulate Gaussian sub-channels from the physical link with strongly diverse transmission capabilities, which leads to significantly improved transmission efficiency, higher tolerable loss, and excess noise. We also investigate a modulation-variance adaption technique within the AMQD scheme, which provides optimal capacity-achieving communication over the sub-channels in the presence of a Gaussian noise.

9123-7, Session 2

The braided single-stage protocol for quantum-secure communication

Bhagyashri A. Darunkar, Pramode K. Verma, The Univ. of Oklahoma, Tulsa (United States)

Securing information in transit is an increasingly important need of the modern society. Quantum cryptography is the only known means to provide unconditional security. Contemporary cryptographic solutions based on the BB'84 protocol rely on the availability of single photons to carry information. This constraint restricts the distance and speed over which quantum cryptography can be offered, resulting in limiting its application to Quantum Key Distribution over short distances as opposed to quantum communication.

This paper presents the concept of a braided single-stage protocol for quantum-secure communication. It is based on the three-stage protocol that uses a multi-photon approach to provide quantum-secure communication. The multi-photon three-stage protocol results in the system not suffering from the distance and speed limitation associated with the BB'84 protocol. However, the three-stage protocol requires information to traverse the transmission link between the two communicating endpoints three times. The concept of braiding results in the protocol transferring quantum-secure information in just one step without the need for it going back and forth three times. The braided single-stage protocol requires the use of the three-stage protocol technique just once, initially, to exchange an initializing vector prior to its operation.

The braided single-stage protocol has been implemented in the laboratory using optical devices and components over free space. In brief the proposed protocol capitalizes on strengths of the three stage protocol and while using the concept of braiding to transfer quantum-secure information in a single step.

9123-8, Session 2

Dual compressible hybrid quantum secret sharing schemes based on extended unitary operations

Hong Lai, Mehmet Orgun, Macquarie Univ. (Australia); Liyin Xue, Australian Taxation Office (Australia); Jinghua Xiao, Beijing Univ. of Posts and Telecommunications (China); Josef Pieprzyk, Macquarie Univ. (Australia)

A crucial issue with hybrid quantum secret sharing schemes is the amount of data that is allocated to the participants. The smaller the amount of allocated data, the better the performance of a scheme. Moreover, quantum data is very hard and expensive to deal with, therefore, it is desirable to use as little quantum data as possible. To achieve this goal, we first construct extended unitary operations by the tensor product of n,n>=2, basic unitary

operations, and then by using those extended operations, we design two quantum secret sharing schemes. The resulting dual compressible hybrid quantum secret sharing schemes, in which classical data play a complementary role to quantum data, range from threshold to access structure. Compared with the existing hybrid quantum secret sharing schemes, our proposed schemes not only reduce the number of quantum participants, but also the number of particles and the size of classical shares. To be exact, the number of particles that are used

to carry quantum data is reduced to 1 while the size of classical secret shares also is also reduced to $frac{l-2}{m-1}$ based on ((m+1,n')) threshold and to (l-2)/(r_{2}) (where /(r_{2} is the number of maximal unqualified sets) based on adversary structure. Consequently, our proposed schemes can greatly reduce the cost and difficulty of generating and storing EPR pairs without weakening the security of quantum secret sharing.

9123-10, Session 3

Example of lumped parameter modeling of a quantum optics circuit

Paul J. Werbos, National Science Foundation (United States)

Is it ever possible for a simple lumped parameter model of a circuit to yield correct quantum mechanical predictions of its behavior, when there is quantum entanglement between components of that circuit? This paper shows that it is possible in a simple but important example – the circuit of the original Bell's Theorem experiments, for ideal polarizers.

Correct predictions emerge from two alternative simple models, based on classical Markov Random Fields across space-time. These models are essentially a translation of the picture of Klyshko, widely used in the work of Yanhua Shih and Morton Rubin, into formal, classical lumped parameter models. Exact agreement with quantum mechanics does not violate Bell's Theorem itself, because the interplay between initial and final outcomes in these calculations does not meet the classical definition of time-forwards causality. Both models raise interesting questions for future research. The final section discusses several possible directions for following up on these results, both in lumped system modeling and in more formal and general approaches.

9123-11, Session 3

Implications of the Landauer limit for quantum logic

Fabian M. Mihelic, The Univ. of Tennessee Graduate School of Medicine (United States)

The design of any system of quantum logic must take into account the implications of the Landauer limit for logical bits. Useful computation implies a deterministic outcome, and so any system of quantum computation must produce a final deterministic outcome, which in

a quantum computer requires a quantum decision that produces a deterministic qubit. All information is physical, and any bit of information can be considered to exist in a physicality represented as a decision between the two wells of a double well potential in which the energy barrier between the two wells must be greater than kT•ln2. Any proposed system of quantum computation that does not result in such a deterministic outcome can only be considered stochastically as a probability distribution (i.e. a wave function). An example of such determinism in a quantum logic system is theorized to exist in the DNA molecule, where the decoherence of quantum decision results in an enantiomeric shift in the deoxyribose moiety that is appropriate to the Landauer limit.

9123-12, Session 3

Building two-photon qubit from incoherent thermal fields

Tao Peng, Hui Chen, Jane Sprigg, Yanhua Shih, Univ. of Maryland, Baltimore County (United States)

During the last 20 years, quantum computing has attracted much attention due to its promising super-fast calculation in those algorithms that need exhaustion, such as factoring a large number. Similar to classical computer, quantum computing also need binary basis, which are implemented with two orthogonal quantum states called qubits. To perform a real quantum computing, a large number n-qubits are required. The n-qubit states construct a Hilbert space with dimension of N=2^n. One promising way to build an N-qubit system is using entangled photons. However, produce a large number n-photon entangled state is still a challenge.

Recently, a number of experiments successfully simulated entangled photons' behaviors with thermal light, and acquired similar quantum effects. These inspire us using thermal photons to build n-qubits. An n-qubit system can be built with n independent and incoherent thermal fields. Each field can be horizontal or vertical polarized. Although there are still challenges and debates, this reported experiment provides a quit interesting and exciting result.

The reported experiment is a principle demonstration of n-photon qubit of thermal light. In this experiment, with the help of Franson-type interferometer and the positive-negative fluctuation correlation protocol, two qubits are prepared from two incoherent and orthogonal polarized thermal fields. We demonstrated a classic Franson interference in which a pair of photons from incoherent thermal fields takes the long-long path and/or the short-short path of the interferometer only. The observed visibility of two-photon interference exceeds 71% indicating a Bell type correlation in space-time variables.

9123-13, Session 3

Progress towards a quantum memory with telecom-wavelength conversion

Daniel T. Stack, Qudsia Quraishi, Patricia J. Lee, U.S. Army Research Lab. (United States)

Fiber-based transmission of quantum information over long distances may be achieved using quantum memory elements and quantum repeater protocols. However, atom-based quantum memories typically involve interactions with light fields outside the telecom window where attenuation in optical fibers is at a minimum. We report on progress towards a quantum memory based on the generation of 780 nm spontaneously emitted single photons by an off-resonant Raman beam interacting with a cold Rb ensemble. The single photons are then frequency-converted into telecom photons (via difference frequency generation in a PPLN crystal), sent through a 13 km fiber, and then converted back to 780 nm photons (via sum frequency generation in a PPLN crystal). Finally, the atomic state is read out via the interaction of another off-resonant Raman beam with the quantum memory. With such a system, it will be possible to realize a long-lived quantum memory that will allow transmission of quantum information over many kilometers with high fidelity, essential for a scalable, long-distance quantum network.

9123-14, Session 3

A 3D topological insulator quantum dot for optically controlled quantum memory and quantum computing

Hari P. Paudel, Michael N. Leuenberger, Univ. of Central Florida (United States)

We present the model of a quantum dot (QD) consisting of a spherical core-bulk heterostructure made of 3D topological insulator (TI) materials, such as PbTe/Pb_{0.31} Sn_{0.69}Te, with bound massless and helical Weyl states existing at the interface and being confined in all three dimensions. The number of bound states can be controlled by tuning the size of the QD and the magnitude of the core and bulk energy gaps, which determine the confining potential. We demonstrate that such bound Weyl states can be realized for QD sizes of few nanometers. In contrast to topologically trivial semiconductor QDs, the confined massless Weyl states in 3D TI QDs are localized at the interface of the QD and exhibit a mirror symmetry in the energy spectrum. We find that strict optical selection rules give rise to the Faraday effect due to Pauli exclusion principle. We show that the semi-classical Faraday effect can be used to read out spin quantum memory. When a 3D TI QD is embedded inside a cavity, the single-photon Faraday rotation provides the possibility to implement optically mediated quantum teleportation and quantum information processing with 3D TI QDs, where the qubit is defined by either an electron-hole pair, a single electron spin, or a single hole spin in a 3D TI QD. Remarkably, the combination of inter- and intraband transition gives rise to a large dipole moment of up to 450 Debye. The strong-coupling regime can be reached for a cavity quality factor of Q≈10^4 in the infrared wavelength regime.

9123-15, Session 4

New results in remote quantum sensing

Gerald N. Gilbert, The MITRE Corp. (United States)

It was shown several years ago that the use of photonic N00N states as probe signals for remote quantum sensing intended to achieve increased phase sensitivity encounters problems when realistic atmospheric loss is taken into account. It was shown that in the presence of non-vanishing photon attenuation the Heisenberg limit is never achieved, and that attenuated N00N states actually produce worse phase estimates than equally attenuated N-photon separable states unless the transmittance of the medium is sufficiently high. In this talk we examine a new approach that may circumvent these problems thus possibly enabling remote quantum sensing in realistic environments.

9123-16, Session 4

Characterization of photons generated in spontaneous parametric down-conversion

Mark Bashkansky, Igor Vurgaftman, U.S. Naval Research Lab. (United States); J. Reintjes, Sotera Defense Solutions (United States)

Low-photon-number sources can exhibit non-classical and counterintuitive behavior that can be exploited in the developing field of quantum technology. Single photons play a special role in this arena since they represent the ultimate low-photon-number source. They are considered an important element in various applications such as quantum key distribution, optical quantum information processing, quantum computing and intensity measurement standards. Other applications in this developing field are yet to be discovered. True deterministic sources of single photons on demand

are currently an area of intensive research, but remain under development. As a result, researchers commonly default to the well-established workhorse: spontaneous parametric down-conversion generating entangled signal-idler pairs. Since this source is statistical in nature, it is common to use a detected idler photon to herald the production of a signal photon. The need exists to determine the quality of the single photon state generated in the heralded signal beam. Quite often, the literature reports a "heralded second-order coherence function" of the signal photons conditioned on the idler photons using readily available single-photon detectors. In this work, we examine the relevance of this technique to single-photon characterization and the consequences of the fact that the most commonly used single-photon detectors are not photon-number resolving. Our results show that this method using non-photon-resolving detectors can only be used to characterize certain particular properties of the quantum state.

9123-17, Session 4

Phase manipulation in fluctuation-fluctuation correlation of thermal light

Hui Chen, Tao Peng, Jane Sprigg, Yanhua Shih, Univ. of Maryland, Baltimore County (United States)

The high-order correlation of thermal light originates from the non-trivial correlation of intensity fluctuations.

The intensity fluctuations are caused by mutual correlation of difference subfields within a thermal source, i.e. the phase differences between subfields induces the intensity fluctuations.

Although the phases of individual subfields are not able to be manipulated or measured during the second- or higher-order joint detections, their phase differences are actually controllable.

In the reported experiment, the phase differences between two independent subfields are precisely manipulated, and a sinusoidal correlation function is observed in fluctuation-fluctuation correlation measurement. The visibility is close to 100%.

The study can be easily extended to N-order(more than 2) correlations just by manipulating the phase differences among N subfields.

The experiment demonstrates the fundamental physics of intensity fluctuations and a novel application in high-order correlation, which is giving an exciting 100% visibility.

9123-18, Session 4

Deterministic generation of many-photon GHZ states using quantum dots in a cavity

Michael N. Leuenberger, Mikhail Erementchouk, Univ. of Central Florida (United States); Ahmed Elhalawany, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

We propose a novel theoretical scheme based on the off-resonant interaction of N photons with four InAs/GaAs semiconductor quantum dots (QDs) in an AlGaAs microdisk cavity to create many-photon GHZ states deterministically in the polarization degree of freedom at a wavelength of 1.5 microns for N up to 60, without the need of any projective measurement or local unitary operation. Taking advantage of off-resonant interaction, the time evolution of the N-photon state is robust against decoherence due to exciton-phonon and hyperfine interactions.

However, decoherence due to leakage of the photons out of the cavity is not negligible and is therefore considered. Remarkably, by taking advantage of a cascaded multi-level Landau-Zener transition, we are able to reduce the GHZ state generation time to below 100 ps for N up to 60, which allows for the creation of GHZ states with N up to 60 in cavities with Q=10^6 with fidelity above 70% including decoherence due to leakage.

Our method paves the way to the miniaturization of many-photon GHZ state sources to the nanoscale regime, with the possibility to integrate them on a computer chip based on semiconductor materials.

9123-19, Session 4

Quantum walk search factors in the regime of weak measurement

Debabrata Ghoshal, George Mason Univ. (United States)

Our previous work brought some interesting results of the discrete Quantum Walks in the regime of Weak Measurement (QWWM). Using the knowledge of such results of QWWM, we are now exploring the search algorithms and investigating the factors associated with such walk. The study of such factors like dimensionality, connectivity of the dataset and disorder are already studied by others in the context of general quantum walks. It is our interest to show the similarities and/or differences of such factors of general quantum walks with QWWM. The subject of decoherence in quantum walks is another challenging research topic at present. We are also exploring the topic of decoherence in QWWM.

9123-20, Session 4

Analysis of quantum dot superlattice of quantum information theory

Subhamoy Singha Roy, JIS College of Engineering (India)

The thickness and the doping dependences of the field emission from all the aforementioned cases have been studied for the purpose of relative comparison, taking GaxAsyP1-y and AlAs lattice matched to InP quantum wire superlattice (QWSL) as an example.

9123-21, Session 4

Quantum hyper-entanglement based sensor arrays with reduced measurement time and enhanced signal to interference ratios

James F. Smith III, U.S. Naval Research Lab. (United States)

An array consisting of M sensors made up of quantum mechanical transmitter-detector pairs (TMPs) is considered. Each transmitter-detector pair makes use of one signal and one ancilla photon which are quantum hyper-entangled. The optical or infrared frequency signal photon will be transmitted and used to probe the propagation environment while the ancilla photon will be maintained within the detector. The effect of noise in every mode as well as loss is included. The signal photon will experience classical loss and each ancilla photon will suffer a low level of loss. Forming an array offers the further advantage of a greater reduction in measurement time. It is shown mathematically that in the large d limit, where d is the number of modes, that different TMPs do not interfere with each other implying they can be put close together, i.e., the signal to interference ratio (SIR) is enhanced by a factor of d. Entanglement provides a kind of quantum isolation between TMPs. This permits an enormous reduction in the measurement time by a factor of d times M, reducing imaging to a snapshot at certain ranges. Closed form results for the reduced density operator, probability of detection, probability of false alarm, signal to noise ratio (SNR), SIR, symmetrized logarithmic derivative, quantum Fisher information (QFI), quantum-Cramer-Rao lower bound (QCRLB), quantum Chernoff bound (QCB), and number of required detections based on the QFI and QCB are provided.

9123-22, Session 5

Absence of local energy in elementary spin systems at low temperature

Michael R. Frey, Bucknell Univ. (United States); Masahiro Hotta, Tohoku Univ. (Japan)

Local energy in a component of a multipartite quantum system is the maximum energy extractable by a quantum operation applied locally just to that component. Systems of Heisenberg spin-1/2 particles in thermal equilibrium with a heat reservoir occupy a quantum Gibbs state with a well-defined temperature. In this setting, for general (Kraus, operator-sum) quantum operations applied to a single particle, we find without exception in each of many cases considered that the system temperature must exceed a non-zero threshold for local energy to be present; below this threshold local energy is absent. This threshold varies with the system, depending on the degree of particle coupling and the strength of any external magnetic field. This threshold for local energy is not restricted to systems of just a few particles. In fact, in cases of ring and star spin coupling topologies, local energy is absent at low temperature for systems of arbitrarily many particles.

9123-23, Session 5

Maximal proper acceleration and the quantum-classical boundary

Howard E. Brandt, U.S. Army Research Lab. (United States)

I first review the physical basis for the universal maximal proper acceleration. Next, I introduce a new formulation for a relativistic scalar quantum field which generalizes the canonical theory to include the limiting proper acceleration. This field is then used to construct a simple model of an uncorrelated many-body system. I next argue that for a macroscopic object consisting of more than Avogadro's number of atoms, any supposed quantum state of the object is negligibly small, so that for all practical purposes, the object is best described by classical mechanics. Thus, a new explanation is offered for the quantum-classical transition and the absence of quantum superposition of macroscopic objects in the everyday world.

9123-24, Session 5

A quantum benchmark for the D-Wave computer

Samuel J. Lomonaco Jr., Univ. of Maryland, Baltimore County (United States); Louis H. Kauffman, Univ. of Illinois at Chicago (United States); Omar Shehab, Univ. of Maryland, Baltimore County (United States)

Simon's algorithm is a quantum algorithm that solves Simon's Problem in polynomial time. On the other hand, it is proven that every classical algorithm that solves Simon's Problem will take at least exponential time to complete its task. We propose running Simon's algorithm on the D-Wave. If the resulting running time of the algorithm scales as a polynomial, then this is a strong indicator that the D-Wave is actually a quantum computer.

9123-25, Session 5

Graphical calculi for quantum information and quantum topology

Louis H. Kauffman, Univ. of Illinois at Chicago (United States); Samuel J. Lomonaco Jr., Univ. of Maryland, Baltimore County (United States)

Such calculi were first invented by Roger Penrose as 'abstract tensor calculus' and have many uses in physics and in combinatorial mathematics. These calculi are very close to methods used in knot theory, quantum topology and category theory. This talk will discuss such structures and how they can be used to illuminate many aspects of quantum information including topological quantum computing, teleportation, measurement, entanglement and quantum knots. The key to this approach is to represent a tensor by a planar node or glyph and its indices by graphical edges incident to the nodes. edges that are incident to two nodes correspond to paired tensor indices and would be summed over in an evaluation of the resulting graphical network. Directionality in such networks leads to a category interpretation of the calculus, but our thesis in this talk is that it is most convenient to consider graphical calculi (comparable to tensor networks but more general) and to understand that they fit into categorical frameworks in a multiplicity of ways. We will give examples of applications of these techniques to the Fibonacci model in quantum computing, to the formalism of teleportation and to other aspects of entanglement.

9123-26, Session 5

Global effects of mathematical locality and number scaling on physical systems and on space time

Paul Benioff, Argonne National Lab. (United States)

A stronger foundation for earlier work on local availability of mathematics and scaling, and new results, will be described. Gauge theory considerations lead to use of local mathematical universes, U_{x} at each point ,x, of a flat 4 dimensional manifold, M. Each U_{x} contains representations of mathematical systems that include numbers in their description. Coordinate systems, defined by charts, that map M to {R}^{4}_{x} are included. For each pair, x,y of points of M and each type, S, of mathematical system, isomorphisms, F_{S,y,x}, that map a structure, S_{x} onto S_{y} in U_{y}, define the notion of "same value as" between elements of S_{x} and S_{y}.

Global mathematical entities that belong to no U_{x} are defined. These include coordinate charts, fields, wave packets, etc. Any entity represented as a function with domain M, or is an integral over space time is included. Global coordinate charts, phi, are defined where for each y in M, phi(y) is a location in {R}^{4}_{y}. For each point, x, phi is equivalent to a coordinate system on {R}^{4}_{x} in U_{x}.

Space time dependent scaling of numbers expresses the freedom to choose scaled number structures of each type at each point of M. The existence of scaled structures of each number type, satisfying relevant axioms, follows, provided basic operations and relations are also scaled.

As noted in earlier talks, Number scaling is described as a scalar boson field. Theoretical descriptions of quantum systems and geometry are affected. The new result is that scaling distorts maps of global coordinate charts onto {R}^{4}_{x} in each U_{x}. The result is a manifold in U_{x} that represents a distorted space time. With scaling, this is the global arena for describing physical dynamics and kinematics in U_{x}.

9123-27, Session 5

Topological quantum computation of the Dold-Thom functor

Juan F. Ospina, Univ. EAFIT (Colombia)

A possible topological quantum computation of the Dold-Thom functor is presented. The method that will be used is the following: a) Certain 1+1-topological quantum field theories valued in symmetric bimonoidal categories are converted into stable homotopical data, using a machinery recently introduced by Elmendorf and Mandell; b) we exploit, in this framework, two recent results (independent of each other) on refinements of Khovanov homology: our refinement into a module over the connective k-theory spectrum and a stronger result by Lipshitz and Sarkar refining Khovanov homology into a stable homotopy type; c) starting from the Khovanov homotopy the Dold-Thom functor is constructed; d) the full construction is formulated as a topological quantum algorithm. It is conjectured that the Jones polynomial can be described as the analytical index of certain Dirac operator defined in the context of the Khovanov homotopy using the Dold-Thom functor. As a line for future research is interesting to study the corresponding supersymmetric model for which the Khovanov-Dirac operator plays the role of a supercharge.

9123-28, Session 5

Quantum walk in optical quantum device

Nan Wu, Haixing Hu, Ping Xu, Fangmin Song, Nanjing Univ. (China); Xiangdong Li, New York City College of Technology (United States) and City Univ. of New York (United States)

We study a probability model of quantum walk by using an integrated optical quantum device, which can demonstrates the quantum-walk based searching algorithm in 2-D glued trees within the device. We discuss that the integrated optical device can be a good candidate to implement the quantum-walk algorithm.

9123-29, Session 5

Logical synchronization: how evidence and hypotheses steer atomic clocks

John M. Myers, Harvard Univ. (United States)

Based on a recent proof of unknowability in the choice a wave function to explain given evidence, we show that explanations of clock readings, whether framed in concepts of quantum theory or in a metric theory of gravitation, involve hypotheses beyond the reach of logic, subject to testing and subsequent revision in an endless cycle. While explanations are subject to an endless evolution, the back-and-forth of hypothesis making and evidence gathering to do with the steering of atomic clocks proceeds within fixed "machinery," cartooned here by a Turing machine modified to communicate, subject to phasing constraints on its reception of logical symbols. In an example of clock-carrying spaceships, phasing constraints impact communications necessary to the gathering of evidence to be explained by a metric tensor field, while a hypothesized metric tensor field underpins an aiming point toward which to steer the spaceships with their clocks so as to maintain the phasing constraints.

Variation in spacetime curvature is shown to limit the bandwidth of a feedback loop that steers the spaceships and their clocks.

Conference 9124: Satellite Data Compression, Communications, and Processing X

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9124-1, Session 1

A theory of least squares target-specified virtual dimensionality in hyperspectral imagery

Drew Paylor, Chein-I Chang, Univ. of Maryland, Baltimore County (United States)

Virtual dimensionality (VD) has been widely used to determine the number of endmembers. Unfortunately, VD was originally defined as the number of spectrally distinct signatures which were not specifically defined. Accordingly, a spectrally distinct signature does not necessarily imply an endmember. In other words, VD varies with how a spectrally distinct signature is defined. As a result, if a spectrally distinct signature is defined as an anomaly, VD for anomalies is certainly different from VD for endmembers. This paper develops a theory for least squares (LS) target-specified VD where a spectrally distinct signature is defined by an LS-generated target signature which can be generated by an LS-based unsupervised target detection algorithm. Three such LS-based algorithms are of interest, automatic target generation process (ATGP), unsupervised non-negativity constrained least squares (UNCLS) and unsupervised fully constrained least squares (UFCLS). The determination of VD is then formulated as a binary hypothesis testing problem where a Neyman Pearson test is performed to see if target signatures generated by ATGP, UNCLS or UFCLS pass or fail the test for each spectral band. When a test fails for a particular spectral band, it indicates that there is a target signature present in this band. The value of VD is then determined by the number of spectral bands that the test fails. In order to evaluate the theory, synthetic and real hyperspectral image experiments are conducted to perform analysis.

9124-2, Session 1

Investigation on the GPS single scattering from a 2D largescale sea surface

Yiwen Wei, Li-Xin Guo, Xidian Univ. (China)

Global positioning system (GPS) signals reflected from the ocean surface can be used for various remote sensing purposes. In this paper, we develop a facet model to simulate the received GPS single from a 2-D largecale sea surface. In this model, the sea surface is envisaged as a two-scale profile on which the long waves are locally approximated by planar facets. The microscopic profile within a facet is assumed to be represented by a set of sinusoidal ripple patches. The complex reflective function of each modified facet is evaluated by a modified formula of the original Bass and Fuks' two-scale model, in which the phase factor of each facet is with the capillary wave modification. The scattering field and the bistatic scattering coe?cient of facet model is derived in detail. With received GPS single, we give a detail analysis of the polarization property, the scattering property of GPS scattering signal over the sea surface.

9124-3, Session 1

Applying the hyperspectral region growing algorithm to oil segmentation

Meiping Song, Wei Xu, Dalian Maritime Univ. (China); Haimo Bao, Dalian Nationalities Univ. (China)

It has always been a hot topic to separate the hyperspectral image effectively. Although there are already many common method for this problem, most of them can not work well for the airborne hyperspectral image for oil spill on the sea. A high dimensional region growing segmentation algorithm is prompted for the hyperspectral image, considering the features of oil spill image. In this method, the original seed is computed out automatically by endmember extraction algorithm, and the Euclid distance combined with the shape spectral angle cosine is used to define the growing rule. At last, a new growing pattern is presented according to the influence of waves. Not only the high dimensions information is taken into consideration in this algorithm, but also its automaticity is improved. The results on marked hyperspectral image and the actual oil spill hyperspectral images all prove the efficiency of the algorithm.

9124-4, Session 1

High-resolution remote sensing image restoration based on double-knife-edge method

Shaohui Zhang, Lin Wang, Qiuhua Luo, Xiaopeng Shao, Xidian Univ. (China)

The Point Spread Function (PSF) is one of the key indicators characterizing the signal transfer characteristics of an imaging system. Edge method is applicable to calculate the PSF of the remote sensing imaging systems for its easy implement and robust noise-resistant ability. In this paper, a Double-Knife-Edge method is proposed to recover the degraded images using a precise estimated PSF of the imaging system. The exact motion-blur direction is estimated by image differentiation firstly. Two orthogonal edges, one of which is in the same direction as the main motion-blur, are picked up from the candidate edges via Hough transform and employed to obtain edge spread functions (ESF). Derived from these ESFs, a more accurate PSF is used to deconvolute the degraded image by an image restoration algorithm based on total variation (TV) deconvolution which is capable of suppressing the artifacts and noise. The experiment results show that this algorithm is adaptive and efficient to reconstruct remote sensing images, and the reconstructed image has better PSNR, MSE and MTF than the original degraded image.

9124-5, Session 1

Scattering characteristics of Gaussian beam from two dimensional dielectric rough surfaces based on the two-scale method

Longxiang Linghu, Zhensen Wu, Yuanyuan Zhang, Xidian Univ. (China)

The scattering characteristic of paraxial Gaussian beam from two dimensional dielectric rough sea surface is studied in this paper. The Kirchhoff approximation theory and the small perturbation approximation(SPA) theory for rough surface scattering by an incident Gaussian beam instead of a plane wave are developed based on conventional Kirchhoff scattering theory, conventional SPA scattering theory and plane wave spectrum expansion method. As a application, The Two-scale Method based on Kirchhoff theory and SPA theory is applied to calculate the backscattering radar cross section of Gaussian beam scattering from dielectric rough surfaces change with the scattering azimuth angle ,the frequency and the wind speed. A close form for the normalized radar cross section is derived when the linear dimension of rough surface patch is larger twice than the beam size. In the same scattering conditions, we compared the backscattering radar cross section between the Gaussian beam and plane wave to prove that our results are correct. The results show that the radio between the beam size and the surface height correlation length play an important role in the scattering characteristic of the Gaussian beam for two dimensional dielectric rough surface. It is shown that provided the incident Gaussian beam size is much larger compared with the surface height correlation length, the normalized scattering cross section is the same as for an incident plane wave.

9124-6, Session 1

Multidimensional edge detection operators

Sungwook Youn, Chulhee Lee, Yonsei Univ. (Korea, Republic of)

In remote sensing, modern sensors produce multi-dimensional images. For example, hyperspectral images contain hundreds of spectral images. In many image processing applications, segmentation is an important step since it divides an image into meaningful homogeneous regions. Usually, image segmentation has been developed for one-dimensional images. For multi-dimensional images, the output images of spectral band images are combined under certain rules or using decision fusions. Also, edge detection is a difficult task since images may contain complex scenes without clear boundaries.

In this paper, we proposed a new edge detection algorithm for multi-dimensional images using second-order statistics. First, we reduce the dimension of input images. For example, we can use principal component analysis to reduce the dimension. Then we apply multi-dimensional edge detection operators which utilize second-order statistics. Experimental results show promising results compared to conventional one-dimensional edge detectors such as the Sobel filter.

9124-7, Session 2

Efficient lossy compression implementations of hyperspectral images: tools, hardware platforms, and comparisons

Jose F. Lopez, Univ. de Las Palmas de Gran Canaria (Spain)

Efficient onboard satellite hyperspectral image compression represents a necessity and a challenge for current and future space missions. Therefore, it is mandatory to provide hardware implementations for this type of algorithms in order to achieve the constraints required for onboard compression. In this work, we implement the Lossy Compression for Exomars (LCE) algorithm on an FPGA by means of high-level synthesis (HSL) in order to shorten the design cycle. Specifically, we use CatapultC HLS tool to obtain a VHDL description of the LCE algorithm from C-language specifications. Two different approaches are followed for HLS: on one hand, introducing the whole C-language description in CatapultC and on the other hand, splitting the C-language description in functional modules to be implemented with CatapultC, connecting and controlling them by an RTL description code without HLS. In both cases the goal is to obtain an FPGA implementation. We explain the several changes applied to the original C-language source code in order to optimize the results obtained by CatapultC for both approaches. Experimental results show low area occupancy of less than 15% for a SRAM-based Virtex-5 FPGA and a maximum frequency above 80 MHz. Additionally, the LCE compressor was implemented into an RTAX2000S antifuse-based FPGA, showing an area occupancy of 75% and a frequency around 53 MHz. All these serve to demonstrate that the LCE algorithm can be efficiently executed on an FPGA onboard a satellite. A comparison between both implementation approaches is also provided. The performance of the algorithm is finally compared with implementations on other technologies, specifically a graphics processing unit (GPU) and a single-threaded CPU.

9124-8, Session 2

Lossy hyperspectral image compression using improved classified DCT and 3DSPIHT

Keyan Wang, Zifan Hu, Ran Han, Jing Zhang, Yunsong Li, Xidian Univ. (China)

An improved classified DCT-based hyperspectral image compression algorithm is proposed. As variation of pixel values in one band of the hyperspectral image is large, the traditional DCT is not very efficient for spectral decorrelation(compared with the optimal KLT). The proposed algorithm is designed to deal with this problem. This algorithm begins with a 2D wavelet transform in spatial domain. After that, the obtained spectral vectors are clustered into different subsets based on their statistics characteristics, and a 1D-DCT is performed on every subset. The classified algorithm consists of three steps to make sure the statistics features fully used. In step1, a mean based clustering is done to obtain basic subsets. Step2 refines clustering by the range of spectral vector curve. Spectral vector curves, whose maximum and minimum values are located in different intervals, are separated in step3. Since vectors in one subset are close to each other both in values and statistic characteristics, which means a high relationship within one subset, the performance of DCT can be very close to KLT, but the computation complexity is much lower. After the DWT and DCT in spatial and spectral domain, an appropriate 3D-SPIHT image coding scheme is applied to the transformed coefficient to get a bit stream within scalable property. Results show that the proposed algorithm retains all the desirable features of compared state-of-art algorithms despite its high efficiency, and can also have a high performance over the non-classified ones at the same bitrate.

9124-9, Session 2

Hyperspectral data compression using lasso algorithm for spectral decorrelation

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Among discrete orthogonal transforms, Karhunen-Loeve transform (KLT) achieves the most optimal spectral decorrelation for hyperspectral data compression with minimum mean square error. A common approach for those spectral decorrelation transform techniques such as KLT is to select m coefficient using some threshold value and then treating the rest of the coefficients as zero, this will result in loss of information. In order to preserve more information on small target data, this paper focused on a new technique called joint KLT-Lasso. The Lasso was applied to KLT coefficient. Sparse loadings were obtained using the Lasso constraint on KLT regression coefficients and more coefficients were shrunk to exact zero. The goal of our new method is to introduce a limit on the sum of the absolute values of the KLT coefficients and in which some coefficients consequently become zero without using any threshold value. A simulation on different hyperspectral data showed encouraging results.

9124-10, Session 2

Wavelet-based compression of multichannel climate data

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To compress multichannel climate data, the wavelet subband arranging technique is proposed.

The proposed technique is based on the wavelet transform, and is designed to deal with the large amount of multichannel climate data for transmission, and real-time analysis.

At first, the wavelet transform is applied on multichannel climate data. Then, to simultaneously compress the data, the wavelet subbands of channels should be arranged appropriately. To arrange the wavelet subbands, the largest threshold from every channel is calculated.

A partial ordering of the wavelet coefficients plays a key role in the proposed approach. The partial ordering is performed based on a set partitioning sorting, ordered bit stream transmission, and exploitation of self-similarity across the wavelet subbands. In fact, the wavelet coefficients are organized in hierarchies.

In comparison with other compression methods, the proposed technique is faster due to the evaluation way of the wavelet coefficients in the sorting procedure. Moreover, execution time of compression for the proposed approach is short compared with 2-D or 3-D compression algorithms.

Additionally, the proposed method reduces the number of transmitted or stored bits in a bit stream. Furthermore, arranged wavelet subbands of input channels provide more efficient multichannel data compression, because appropriate parent-offspring relations among wavelet coefficients are constructed in the hierarchical structure.

To test and evaluate the proposed approach, data from the Nevada climate change database is utilized. Based on results, the proposed technique can be an appropriate choice for compression of multichannel climate data with significant low compressed data rate.

9124-11, Session 3

Anomaly discrimination in hyperspectral imagery

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Anomaly detection finds data samples whose signatures are spectrally distinct from their surrounding data samples. Unfortunately, it cannot discriminate the anomalies it detected one from another. In order to accomplish this task it requires a way of measuring spectral similarity such as spectral angle mapper (SAM) or spectral information divergence (SID) to determine if a detected anomaly is different from another. However, this arises in a challenging issue of how to find an appropriate thresholding value for this purpose. Interestingly, this issue has not received much attention in the past. This paper investigates the issue of anomaly discrimination which can differentiate detected anomalies without using any spectral measure. The ideas are to makes use unsupervised target detection algorithms, Automatic Target Generation Process (ATGP) and Unsupervised Fully Constrained Least Squares (UFCLS) coupled with an anomaly detector to distinguish detected anomalies. Experimental results show that the proposed methods are indeed very effective in anomaly discrimination.

9124-12, Session 3

MTF compensation method utilizing the curved edge for high-resolution satellite image recovery

Qiuhua Luo, Lin Wang, Hong Yang, Shaohui Zhang, Xiaopeng Shao, Xidian Univ. (China)

The low resolved satellite images caused by serious degradation in remote sensing weaken its utilities in practice. An effective algorithm of high resolution remote sensing image reconstruction is proposed to recover the degraded images using a precise estimated modulated transfer function (MTF) of the imaging system from a curve knife edge. Choosing a proper curve edge is most important step in image reconstruction. A curve edge, even irregular in shape, from which a better edge spread function (ESF) can be obtained, is automatically picked up from the edge information according to the neighborhood features of the image first. The estimated MTF derived from the above ESF is employed to deconvolute the degraded image. To suppress the artifacts and noise, the total variation (TV) method is applied in reconstruction as well. The advantage of this algorithm is that a curve edge is chosen automatically and robustly among many candidate edges, which can provide a higher precision in comparison to straight edge. The experiments show that this algorithm is suitable to recover a high-resolved image with a high signal-to-noise ratio (SNR) from a degraded remote sensing image.

9124-13, Session 3

Adaptive sparse signal processing of satellite-based radiofrequency (RF) recordings of lightning events

Daniela I. Moody, David A. Smith, Los Alamos National Lab. (United States)

Ongoing research at Los Alamos National Laboratory studies the Earth's radiofrequency (RF) background utilizing satellite-based RF observations of terrestrial lightning. Such impulsive events are dispersed through the ionosphere and appear as broadband nonlinear chirps at a receiver on-orbit. They occur in the presence of additive noise and structured clutter, making their classification challenging. The Fast On-orbit Recording of Transient Events (FORTE) satellite provided a rich RF lightning database. Application of modern pattern recognition techniques to this database may further lightning research in the scientific community, and potentially improve on-orbit processing and event discrimination capabilities for future satellite payloads. We now develop new event classification capability on the FORTE database, with the initial goal of improved feature extraction using sparse representations. We compare classification scenarios designed to identify the presence and capture the dynamic behavior of standard lightning event types, while remaining robust to changes in clutter and noise levels. Conventional data representations using analytical dictionaries, such as a short-time Fourier basis or wavelets, are not comprehensively suitable for analyzing broadband RF transients. We propose two alternative approaches based on dictionaries adapted to data. A first option is using analytical, over-complete dictionaries, which yield sparse representations by design. A second option is learning discriminative dictionaries directly from data. A pursuit search over either dictionary generates sparse classification features. We present comparative results on real RF satellite data, and discuss robustness to variability in lightning RF emissions.

9124-14, Session 3

A compressed coded aperture imaging warning system

Xiaopeng Shao, Juan Du, Lin Wang, Xidian Univ. (China)

Compressed coded aperture based imaging warning system with a low resolution optical sensor is proposed in this paper, which is specifically designed to support the demands of rapid, high resolution, long-range detection and warning in complex battlefield environment. After analyzing of the tactic specification and the technical specification, the key techniques of this novel alarming system are discussed and designed, including optical imaging module, image-processing module, alarming control module and interfaces unit. The optical imaging module is used for image compression, then, the coded image will be mathematically reconstructed to a high resolution image by the image-processing module. The presented super-resolution reconstruction algorithm is efficient and robust. Combining compressed coded imaging simulation and coded image super-resolution reconstruction, experiments show that the compressed coded aperture imaging alarming system has a longer detectable range, which is potential in the defence of important targets.

9124-15, Session 3

An adaptive filtering based on generalized sidelobe cancellation for target detection of hyperspectral images

Lena Chang, Zay-Shing Tang, National Taiwan Ocean Univ (Taiwan); Yang-Lang Chang, National Taipei University of Technology (Taiwan)

In the study, we proposed an adaptive filter with multiple constrains based on the generalized sidelobe canceller (GSC) structure for target detection of hyperspectral images. The proposed filtering approach can alleviate the performance degradation in target detection caused by estimation errors in spectral signature of the desired target or some random noise by unknown interference. First, we design an optimal filter to minimize the interference effect with multiple constrains including unit gain response on desired target and null response on undesired targets. The optimal filter can detect the desired target, suppress the undesired targets and minimize the interference effect. Then, an adaptive filter with GSC structure is proposed to transform the constrained minimization problem into an equivalent

unconstrained minimization. The structure of GSC contains two branches: the upper branch is a filter with fixed weights Wf designed by multiple constrains to reserve the desired target and interference; the lower branch contains a blocking matrix B and an adaptive filter with weights Wa. Matrix B blocks the desired target and preserve the interference. The adaptive filter can be designed to minimize the interference effect without constrains. Simulations validate the effectiveness of the proposed adaptive filter with GSC structure which is robust to the random errors in spectral signature of the desired target.

9124-16, Session 4

On the acceleration of the NFINDR algorithm for hyperspectral endmember extraction

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Endmember extraction represents a critical step within the process of linearly unmixing a given hyperspectral image because of two main reasons. The first one is due to the need of computing a set of accurate endmembers in order to further obtain confident abundance maps. The second one refers to the huge amount of operations involved in this time-consuming process.

Winter's NFINDR represents one of the most popular alternatives for the process of inducing the endmembers of a hyperspectral image. It is based on finding the simplex of maximum volume that can be inscribed within the hyperspectral data set, being its vertices the sought endmembers. For completing this process, the NFINDR algorithm requires the image to be first dimensionality reduced to p-1 bands, where p equals to the number of endmembers of the targeted scene.

In order to reduce the computational load of the NFINDR algorithm, this work proposes to wisely use the information obtained after the dimensionality reduction step together with a preprocessing stage based on the Automatic Target Generation Procedure (ATGP) algorithm in order to obtain the first p-2 endmembers of the image, and then, to run the NFINDR algorithm in order to uncover the remaining endmembers. The results obtained with synthetic images demonstrate that a reduction in the computational load of up to 87% can be achieved when compared with the original NFINDR algorithm without compromising the accuracy of the extracted endmembers. Moreover, the results obtained with the well-known Cuprite dataset also corroborate the benefits of our proposal.

9124-17, Session 4

Endmember variability resolved by pixel purity index in hyperspectral imagery

Yao Li, Shih-Yu Chen, Cheng Gao, Chein-I Chang, Univ. of Maryland, Baltimore County (United States)

Endmember variability presents a great challenge in endmember extraction since a true endmember may be contaminated by many unknown factors. This paper develops a pixel purity index (PPI) based approach to resolving this issue. It is known that endmember candidates must have their PPI counts greater than 0. Using this fact we can starts with all data samples with PPI counts greater than 0 and cluster them into p endmember classes where the value of p can be determined by virtual dimensionality (VD). We further develop an endmember identification algorithm to select true endmembers from these p endmemberes. So, in our proposed technique three state processes are developed. It first uses PPI to produce a set of endmember candidates and then develops a clustering algorithm to group PPI-generated endmember candidates into p endmember classes and finally concludes by designing an algorithm to extract true endmembers from the p endmember classes.

9124-18, Session 4

On performance improvement of vertex component analysis-based endmember extraction from hyperspectral imagery

Qian Du, Mississippi State Univ. (United States); Nareenart Raksuntorn, Suan Sunandha Rajabhat Univ. (Thailand); Nick Younan, Mississippi State Univ. (United States)

Spectral mixture analysis is one of the major techniques in hyperspectral remote sensing image analysis. Endmember extraction for spectral mixture analysis is a necessary step when endmember information is unknown. If endmembers are assumed to be pure pixels present in an image scene, endmember extraction is to search the most distinct pixels. Popular algorithms using the criteria of simplex volume maximization (e.g., N-FINDR) and spectral signature similarity (e.g., Vertex Component Analysis) belong to this type. N-FINDR is a parallel-searching method, where all the endmembers are determined simultaneously. VCA is a sequential-searching method, finding endmembers one after another, which can greatly save computational cost. In this paper, we focus on VCA-based endmember extraction. In particular, we propose a new searching approach that makes the extracted endmembers more distinct. This is fulfilled by integrating the joint and pairwise orthogonal subspace projection (OSP)-based distance metrics for endmember quality screening. Real data experiments show that it can improve the quality of extracted endmembers.

9124-19, Session 4

Fisher's ratio-based criterion for finding endmembers in hyperspectral imagery

Cheng Gao, Shih-Yu Chen, Chein-I Chang, Univ. of Maryland, Baltimore County (United States)

Endmember extraction has recently received considerable interest in hyperspectral imagery. However, several issues in endmember extraction may have been overlooked. The first and foremost is the use of endmember extraction. Many algorithms claimed to be endmember extraction algorithms actually do not extract true endmembers but rather find potential endmember candidates, referred to as virtual endmembers (VEs). Secondly, how difficult for an algorithm to find VEs is primarily determined by two key factors, endmember variability and endmember discriminability. While the former issue has been addressed recently in the literature, the latter issue is yet explored and has not been investigated before. This paper re-invents a wheel by developing a Fisher's ratio approach to finding VEs using Fisher's ratio criterion for finding VEs endmembers is defined by ratio of endmember variability to endmember discriminability.

9124-20, Session 4

Progressive band processing of simplex growing algorithm for finding endmembers in hyperspectral imagery

Robert C. Schultz, Marissa Hobbs, U.S. Naval Academy (United States); Chein-I Chang, Univ. of Maryland, Baltimore County (United States)

This paper presents a progressive band processing (PBP) of an endmember extraction algorithm, simplex growing algorithm (SGA), to be called PBP-SGA, which allows users to process SGA band by band progressively. Several advantages can be gained from this approach. First of all, PBP-SGA does not require data dimensionality since PBP begins with a lower band dimension and gradually increases band dimensions band by band progressively until it achieves the desired results. Secondly, PBP can process SGA whenever bands are available without waiting for full band

data information completed. As a result, PBP-SGA can be used for data transmission and communication. Thirdly, PBP –SGA can identify which bands are crucial during the process of endmember extraction. Finally, PBP-SGA provides feasibility of being implemented in real time.

9124-21, Session 4

Relationship between linear spectral unmixing and endmember finding

Hsiao-Chi Li, Shih-Yu Chen, Cheng Gao, Chein-I Chang, Univ. of Maryland, Baltimore County (United States)

Linear spectral unmixing (LSU) and endmember finding are closely related. The link to bridge these two is the same geometric structure, simplex that is used to perform LSU and endmember extraction. Since a fully abundance-constrained LSU (FAC-LSU) performs two physical constraints, Abundance Sum-to-one Constraint (ASC) and Abundance Non-negativity Constraint (ANC) it assumes that all data sample vectors are embraced by a simplex with vertices formed by a set of signatures of interest that are provided a priori and found by in an unsupervised means. In this case, all the data sample vectors inside the simplex are unmixed by their fully constrained abundance fractions, while all data sample vector outside the simplex are considered as unwanted sample vectors such as noisy samples, bad sample vectors. As for endmember extraction it makes use of a simplex to locate and extract endmembers which are assumed to be its vertices due to their signature purity and geometric convexity. In other words, in order to find endmembers we are required to find a largest simplex that include as many data sample vectors so that the vertices of this simplex will be considered endmembers. Such simplex is the one with maximal simplex volume. Interestingly, both LSU and endmemberfinding share one thing in common, which is their use of the same two constraints, ASC and ANC imposed by a simplex. This paper explores such relationship between LSU and endmember finding.

9124-22, Session 4

Nonlinear hyperspectral unmixing based on multiple kernel constrained NMF

Jiantao Cui, Xiaorun Li, Zhejiang Univ. (China); Liaoying Zhao, Junpeng Zheng, Hangzhou Dianzi Univ. (China)

Nonlinear spectral unmixing constitutes an important field of research for hyperspectral imagery. An unsupervised nonlinear spectral unmixing algorithm, namely multiple kernel constrained nonnegative matrix factorization (MKCNMF) is proposed by coupling multiple-kernel selection with kernel NMF. First, with a nonlinear mapping associated with a kernel function, the original nonlinear mixed data is implicitly mapped into a high-dimensional feature space, where the mapped data is linearly mixed. Then the NMF algorithm is used to unmix the mapped data in the feature space. Additionally, a minimum endmember-wise distance constraint is introduced to alleviate the uniqueness problem of NMF in the algorithm. In the MKCNMF, two problems of optimizing matrices and selecting the proper kernel are jointly solved. The kernel selection process is conducted by comparing the objective functions based on different candidate kernels. The projected gradient and multiplicative update methods are respectively used to update the endmember matrix and abundance matrix alternatively. The performance of the proposed unmixing algorithm is evaluated via experiments based on synthetic and real hyperspectral data sets. The experimental results demonstrate that the proposed method yields higher accuracy in terms of spectral angle distance (SAD) compared with some existing unmixing algorithms and the abundance fractions obtained by MKCNMF coincide well with the published geologic maps.

9124-44, Session Posters-Thursday

A novel IR polarization staring imaging system designed by a four-camera array

Xiaopeng Shao, Fei Liu, Pingli Han, Xidian Univ. (China)

A novel IR polarization staring imaging system employing a four-camera-array is designed for target detection and recognition, especially man-made targets hidden in complex battle field. The design bases on the existence of the difference in infrared radiation's polarization characteristics, which is particularly remarkable between artificial objects and the natural environment. The system designed employs four cameras simultaneously to capture the polarization difference to replace the commonly used systems engaging only one camera. Since both types of systems have to obtain intensity images in four different directions (I0 , I45 , I90 , I-45), the four-camera design allows a better real-time capability and lower error without the mechanical rotating parts which is essential to one-camera systems. Information extraction and detailed analysis demonstrate that the caught polarization images include valuable polarization information which can effectively increase the images' contrast and make it easier to segment the target even the hidden target from various scenes.

9124-45, Session Posters-Thursday

Imaging characteristics of ball lens

Qinghui Li, Xiaopeng Shao, Xidian Univ. (China)

A proof-of-concept gigapixel computational camera consisting of a spherical lens shared by several small planar sensors have been reported recently. Because the resolution of spherical lens is fundamentally limited by geometric aberrations, the imaging characteristics of the ball lens is expressed by the geometrical aberrations, in which the general equations for the primary aberration of the ball lens are given. To achieve high quality imaging, the effects of lens shape, stop position, and glass material on the aberrations are discussed, respectively. The third-order and the fifth-order spherical aberration as a function of lens shape and the relative aperture are analyzed as well. The other image evaluation merits, such as the spot diagram, the modulation transfer function(MTF) and the encircled energy are also described.

9124-46, Session Posters-Thursday

Spherical aberration and modulation transfer function

Qinghui Li, Xiaopeng Shao, Xidian Univ. (China)

The fundamental problem of the modulation transfer function(MTF) form the viewpoint of the lens designer is to find relation between the MTF and the geometrical aberrations. Let it be required to develop the spherical aberration into a polynomial expansion. The incoherent point spread function(PSF) of the optical imaging system is derived from the diffraction integral in the presence of aberrations. The optical transfer function(OTF) is the Fourier transform of the PSF, and the modulus of the OTF is the MTF. The relation between the spherical aberration and the MTF is denoted by numerical integration method. The normalized MTF is numerically calculated for various amounts of spherical aberration. A comparison is made between the MTF of the corrected spherical aberration using the optimum design for the minimum root mean square(RMS) wavefront aberration and those for the minimum peak-to-valley(P-V) wave front aberration.

9124-47, Session Posters-Thursday

Focusing through a turbid medium by amplitude modulation with genetic algorithm

Xiaopeng Shao, Wei Jia Dai, Li Gen Peng, Xidian Univ. (China)

Multiple scattering of light in opaque materials such as white paint and human tissue forms a volume speckle field, will greatly reduce the imaging depth and degrade the imaging quality. A novel approach is proposed to focus light through a turbid medium using amplitude modulation with genetic algorithm (GA) from speckle patterns. Compared with phase modulation method, amplitude modulation approach, in which the elements of spatial light modulator (SLM) is either zero or one, is much easier to achieve. Theoretical and experimental results show that, the advantage of GA is more suitable for low the signal to noise ratio (SNR) environments in comparison to the existing amplitude control algorithms such as binary amplitude modulation. The circular Gaussian distribution model and Rayleigh Sommerfeld diffraction theory are employed in our simulations to describe the turbid medium and light propagation between optical devices, respectively. It is demonstrated that the GA technique can achieve a higher overall enhancement, and converge much faster than others, and outperform all algorithms at high noise. Focusing through a turbid medium has potential in the observation of cells and protein molecules in biological tissues and other structures in micro/nano scale.

9124-48, Session Posters-Thursday

Particle swarm optimization for focusing by phase modulation through scattering media

Xiaopeng Shao, Li Gen Peng, Wei Jia Dai, Xidian Univ. (China)

Particle Swarm Optimization (PSO) is exploited in an optical focusing system, by changing the phase of the incident light, which can break the diffraction limit and enhance focal intensity through highly scattering media. To emphasize that the focusing optical system is mainly composed of a spatial light modulator (SLM), a lens and highly scattering media placed behind the lens. The stepwise sequential algorithm and the continuous sequential algorithm are sensitive to noise and the partitioning randomly algorithm and the genetic algorithm converge slowly. Compared with these algorithms theoretically and experimentally, the PSO is robust, effective and able to converge rapidly, which obtains a best solution by following the search for the optimal particle in the solution space. The capacity of beyond-diffraction and increasing intensity of the focus through dynamic scattering media could be conducive to biological microscopy and imaging through turbid environments.

9124-49, Session Posters-Thursday

Pixel-level image registration method of polarization images acquired by a four-camera array

Xiaopeng Shao, Pingli Han, Fei Liu, Xidian Univ. (China)

The aim of polarization imaging is using four different polarized images at 0°, 45°, 90° and 135°, respectively, to compose the DoLP (degree of linear polarization) image and polarization orient image. A common polarization imaging method acquires the different polarized images using a mechanical system to rotate the polarizer to a certain angle. The drawback of this method is the poor precision and much time consuming in implementation. An effective proposal of polarization imaging using a four-camera array is to acquire four different polarized images simultaneously. With partially overlapping FOV (field of view), it's essential to register and reconstruct images with a high precision captured for precise polarization images, which is the emphasis of this research. A pixel-level image matching algorithm is developed which employs the geometric mapping relation between images. Parameters of the mapping relation are firstly calculated, and then pixels of each image obtained are mapped to a virtual digital plane at which precise and resolution enhanced polarization images can be obtained by taking advantage of the pixel deviation and rearranging the pixels. Experimental results demonstrate the algorithm can assist the four-camera array in rendering easily precise and high-resolution polarization images.

9124-50, Session Posters-Thursday

Online visual tracking based on updating with smoothing

Jin Zhang, Kai Liu, Fei Cheng, Yunsong Li, Xidian Univ. (China)

Visual tracking is an important task in computer vision. Despite many researches have been done in this area, some problems remain. One of the problems is drifting. To handle the problem, a new appearance model update method based on a forward filtering backward smoothing particle filter is proposed in this paper. A smoothing of previous appearance model is performed by exploiting information of current frame instead of updating instantly in traditional tracking methods. It has been shown that smoothing based on future observations makes previous and current predictions more accurate, thus the appearance model update by our approach is more accurate. And at the same time, online tracking is achieved compared with some previous work in which the smoothing is done in an offline way. With the smoothing procedure, the tracker is more accurate and less likely to drift than traditional ones. Experimental results demonstrate the effectiveness of the proposed method.

9124-51, Session Posters-Thursday

Random grid ferns for visual tracking

Fei Cheng, Kai Liu, Jin Zhang, Yunsong Li, Xidian Univ. (China)

Visual Tracking is one of the significant research directions in computer vision. Although standard random ferns tracking method obtains a good performance for the random spatial arrangement of binary tests, the locality of image and more information are ignored. This paper proposes a novel spatial arrangement of binary tests to divide the bounding box into grids in order to keep more details of the image. Experimental results show this method can improve tracking accuracy.

9124-23, Session 5

Above the cloud computing orbital services distributed data model

Jeremy Straub, The Univ. of North Dakota (United States)

Technology miniaturization and system architecture advancements have created an opportunity to significantly lower the cost of many types of space missions by sharing capabilities between multiple spacecraft. Historically, most spacecraft have been atomic entities that (aside from their communications with and tasking by ground controllers) operate in isolation. Several notable example exist; however, these are purpose-designed systems that collaborate to perform a single goal. The above the cloud computing (ATCC) concept aims to create ad-hoc collaboration between service provider and consumer craft. Consumer craft can procure processing, data transmission, storage, imaging and other capabilities from provider craft. Because of onboard storage limitations, communications link capability limitations and limited windows of communication, data relevant to or required for various operations may span multiple craft.

This paper presents a model for the identification, storage and accessing of this data. This model includes appropriate identification features for this highly distributed environment. It also deals with business model constraints such as data ownership, retention and the rights of the storing craft to access, resell, transmit or discard the data in its possession. The model ensures data integrity and confidentiality (to the extent applicable to a

given data item), deals with unique constraints of the orbital environment and tags data with business model (contractual) obligation data.

9124-24, Session 5

Parallelized physical optics computations for the RCS prediction of rough surface by CUDA

Xiao Meng, Li-Xin Guo, Xidian Univ. (China)

The problem of wave scattering by rough surfaces has been studied extensively by scientists and engineers because of its wide applications in science and technology. In this letter, the Physical Optics technique, which is a high frequency technique, is presented for analyzing scattering of rough surface. In addition, the compute unified device architecture (CUDA) of NVIDIA takes advantage of the Graphics Processing Units (GPU) for parallel computing, and greatly improve the speed of computation. Because there is a large number of data to deal with, in order to further improve the computational efficiency, a parallelization concept is presented which is based on the utilization of GPU. At last, the simulation time of CPU and GPU are compared, and it can be found that good acceleration effect has been achieved.

9124-25, Session 5

Optimizing weather and research forecast (WRF) Thompson cloud microphysics on Intel Many Integrated Core (MIC)

Jarno Mielikainen, Melin Huang, Bormin Huang, HungLung Allen Huang, Univ. of Wisconsin-Madison (United States)

The Thompson cloud microphysics scheme is a sophisticated cloud microphysics scheme in the Weather Research and Forecasting (WRF) model. The scheme is very suitable for massively parallel computation as there are no interactions among horizontal grid points. Compared to the earlier microphysics schemes, the Thompson scheme incorporates a large number of improvements. Thus, we have optimized the speed of this important part of WRF. Intel Many Integrated Core (MIC) ushers in a new era of supercomputing speed, performance, and compatibility. It allows the developers to run code at trillions of calculations per second using the familiar programming model.

In this paper, we present our results of optimizing the Thompson microphysics scheme on Intel Many Integrated Core Architecture (MIC) hardware. The Intel Xeon Phi coprocessor is the first product based on Intel MIC architecture, and it consists of up to 61 cores connected by a high performance on-die bidirectional interconnect. The coprocessor supports all important Intel development tools. Thus, the development environment is familiar one to a vast number of CPU developers. Although, getting a maximum performance out of MICs will require using some novel optimization techniques. Currently, the Xeon Phi is connected to a CPU via the PCI Express (PICe) bus. However, in the near future a MIC on a socket will be available. Therefore, future MICs don not have to deal with issues related to data transfer over PCIe. In the paper, both computation time and data transfer issues for Thompson microphysics scheme are analyzed in detail.

9124-26, Session 5

Computational design of miniaturized microstrip antenna for satellite communications in the bands S and C

Damian A. Campo, Jose I. Marulanda, Univ. EAFIT (Colombia)

This paper presents a computational model of a microstrip antenna coated with a high dielectric constant thick film. The main objective is to explore an alternative way to miniaturize dimensions considering two different antennas in the S and C bands. Scattering parameters (S-parameters) and radiation patterns were obtained in both cases and were compared to standard microstrip antennas. Finally, the results obtained by simulations show the possibility of reducing the dimensions of the antenna by 22%, data transmission and directivity of the antenna were also improved demonstrating a relatively easy implementation and development.

9124-27, Session 5

Massive parallel implementation of JPEG2000 decoding algorithm with multi-GPUs

Xianyun Wu, Yunsong Li, Kai Liu, Li Wang, Xidian Univ. (China)

JPEG2000 is an important technique for image compression that has been successfully used in many fields. Due to the increasing spatial, spectral and temporal resolution of remotely sensed imagery data sets, fast decompression of remote sensed data is becoming a very important and challenging object. In this paper, we develop an implementation of the JPEG2000 decompression in graphics processing units (GPUs) for fast decoding of block-based parallel compression stream. We use one CUDA block to decode one frame. T2 is still serial decoded while T1 and DWT are parallel processed. Since our encode stream are block-based parallel which means each block are independent with other blocks, we parallel process each block in T1 with one thread. For DWT, we use one CUDA block to execute one line and one CUDA thread to process one pixel. We investigate the speedups that can be gained by using the GPUs implementations with regards to the CPUs-based serial implementations. Experimental result reveals that our implementation can achieve significant speedups compared with serial implementations.

9124-28, Session 5

Using Intel Xeon Phi to accelerate the WRF TEMF planetary boundary layer scheme

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The Weather Research and Forecasting (WRF) model is designed for numerical weather prediction and atmospheric research. The WRF software infrastructure consists of several components such as dynamic solvers and physics schemes. Numerical models are used to resolve the large-scale flow. However, subgrid-scale parameterizations are for an estimation of small-scale properties (e.g., boundary layer turbulence and convection, clouds, radiation). Those have a significant influence on the resolved scale due to the complex nonlinear nature of the atmosphere. For the cloudy planetary boundary layer (PBL), it is fundamental to parameterize vertical turbulent fluxes and subgrid-scale condensation in a realistic manner. A parameterization based on the TEMF that unifies turbulence and moist convection components produces a better result that the other PBL schemes. For that reason, the TEMF scheme is chosen as the PBL scheme we optimized for Intel Many Integrated Core (MIC), which ushers in a new era of supercomputing speed, performance, and compatibility. It allows the developers to run code at trillions of calculations per second using the familiar programming model. In this paper, we present our optimization results for TEMF planetary boundary layer scheme.

9124-29, Session 6

Texture based adaptive lifting wavelet transform for hyperspectral image compression

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Hyperspectral images are rich in texture features. In this paper, a new compression algorithm is proposed to adaptively choose the texture

direction so as to make a direction-adaptive lifting DWT. This method takes advantages of texture features of hyperspectral images. Compared with traditional approaches which only operate lifting DWT upon the vertical and horizontal directions, the proposed compression algorithm can reduce the high frequency energy which contributes better compressive properties. In directional adaptive wavelet transform, the key problem is to determine a block edge expanding principle to ensure a reversible DWT. To deal with this problem, a new edge expansion algorithm is proposed based on the direction features and it is able to recover pixel information for the block edges accurately. After directional adaptive DWT operated in spatial domain, the KLT which is considered as the optimal transform for data compression in a statistical sense is used in spectral domain. To make the bit stream scalable property, a 3D-SPIHT image coding algorithm is applied on the transformed coefficient. Finally, the experiments show that, compared with the traditional DWT algorithm, the proposed method can get a higher SNR with the same compressive properties.

9124-30, Session 6

FPGA based JPEG-LS encoder for lossless and lossy onboard image compression

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This study introduces JPEG-LS encoder for both lossless and lossy image compression. Proposed architecture is fully competible with standard and comprises parallel pipelines for regular and run modes. It simplifies the run-mode calculation with Run-index feedback. Besides, lossy image compression is achieved with single division with proper arrengments and simplifications. Proposed architecture is implemented with FPGA and eligible for high-performance real time encoding.

9124-31, Session 6

Lossless compression of hyperspectral images using edge-based multi-order predictor

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The existing lossless compression methods of hyperspectral images mainly exploited the strong spatial or spectral correlation, but they rarely considered the edge features of the images. In this paper, an edge-based multi-order predictor (EMOP) is presented to utilize the strong correlation of the pixels along an edge. It contains two prediction modes: intra-band and inter-band. In intra-band mode, an improved median predictor (IMP) is adopted which takes not only the horizontal and the vertical edge detection but also the diagonal edge detection into account. In inter-band mode, a multi-order predictor (MOP) with edge detection and analysis is proposed for accounting the spectral redundancy. Due to the fact that edge detection can find gradient between adjoining pixels, MOP uses the edge detection to select optimal context as sharp gradient shows low relationship. MOP is an extension from one-order to multi-order prediction as a process of Wiener filtering. Finally, all predicted residuals are entropy coded. Experimental results show that the proposed method EMOP is effective on both standard AVIRIS 1997 hyperspectral images and the newer CCSDS images to achieve better compression performance.

9124-32, Session 6

Remote sensing image real-time progressive transmission based on multi-threads with retry broken downloads

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With the development of mobile networks, the demand for remote sensing in the mobile terminal is growing increasingly. However, the narrow network bandwidth and the large network data traffic of mobile transmission have become a bottleneck in the transmission of remote sensing image through mobile networks. In order to meet the different needs for different users to the quality of remote sensing images in heterogeneous network environments, an online remote sensing image progressive transmission model is constructed in which remote sensing image compression and decompression are synchronized with transmission. At the same time, a pipeline-based multi-threaded acceleration method has been proposed through solving the asynchronous problem among compression decompression and transmission to improve the efficiency of remote sensing progressive transmission. Furthermore, for the purpose of reducing waiting time consumed in transmission thread and compression thread, the code stream of compressed remote sensing image is divided into small fixed-length packets to transmit. The packet of compressed code stream is sent to client by transmission thread concurrently with the compression procedure through compression thread. Similarly, while the packet being received by receiving thread, the decompression thread is used to decode packets which have been received simultaneously. At last, an idea of retry broken downloads transmission interruption has been implemented to improve end-user interactive experience. Experimental results show that the whole processing speed has been improved remarkably without reducing image transmission quality by using the proposed progressive transmission and real-time compression model based on SPIHT algorithm. On the other hand, this proposed progressive transmission model has done better in visual effect.

9124-33, Session 7

Land cover classification in multispectral satellite imagery using sparse approximations on learned dictionaries

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Techniques for automated feature extraction, including neuroscience-inspired machine vision, are of great interest for landscape characterization and change detection in support of global climate change science and modeling. We present results from an ongoing effort to extend machine vision methodologies to the environmental sciences, using state-of-the-art adaptive signal processing, combined with compressive sensing and machine learning techniques. We use a modified Hebbian learning rule to build spectral-textural dictionaries that are tailored for classification. We learn our dictionaries from millions of overlapping multispectral image patches and then use a pursuit search to generate classification features. Land cover labels are automatically generated using CoSA: unsupervised Clustering of Sparse Approximations. We demonstrate our method on multispectral Worldview-2 data from three Arctic study areas: Barrow, Alaska; the Selawik River, Alaska; and a watershed near the Mackenzie River delta in northwest Canada. Our goal is to develop a robust classification methodology that will allow for the automated discretization of the landscape into distinct units based on attributes such as vegetation, surface hydrological properties (e.g., soil moisture and inundation), and topographic/geomorphic characteristics. In this paper, we evaluate the spectral properties of the clusters and compare them to remote sensing-derived classifications of landscape attributes, in order to interpret and assign land cover categories to the clusters.

9124-34, Session 7

A novel SVM-based classification for hyperspectral image

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With the extensive application of hyperspectral images in the field of image classification, as the most basic and important part, pixel classification of hyperspectral data has become a major research point in the recent years. Traditional classification algorithms are the maximum likelihood classification, the minimize distance and the neural network, etc. However, because of the huge data of the hyperspectral image cube, these traditional algorithms cannot give a classification image with high accuracy. Now Support Vector Machine (SVM) is widely used in the hyperspectral classification due to its high performance. SVM maps the nonlinear problems in the input space into a higher dimension space where they are considered to become linearly separable. In the higher dimension space, a maximum margin hyperplane is created. It is assumed that the larger distance between the two parallel hyperplanes, the smaller total error of the classifier. Actually, the projection can be simulated using a kernel function. There are a great number of kernel functions which can be defined as two kinds of kernels, one being local kernels and the other global kernels. Examples of typical local kernels are Radial basis kernel and Inverse multiquadric kernel and so on. All kernels based on the dot-product are global, for example, Polynomial kernel, Radial Basis Function (RBF) kernel and Sigrnoid kernel, etc. But, due to the complication of the landforms in hyperspectral image, using usual kernel functions, the accuracy of classification is not as high as predicted.

In order to improve the classification performance of SVM, this paper proposes a new kind of kernel function combining with a prior information of the image, which improves the classification accuracy of hyperspectral image, and reduces the classification error probability. Compared with the usual kernel functions, the new kernel function includes more distribution characteristics of the landforms in the image, with a better classification accuracy when the hyperspectral image has a large number of spectral bands and a extremely complex surface features. For making a more exact classification, the new kernel function and usual kernel functions are linear weighted as a hybrid kernel function for hyperspectral classification. In this paper, We propose a set of weighting coefficients so that the hybrid kernel has the best classification image. In the experiment, a simulated hyperspectral image data set and a real hyperspectral image data are used to prove the accuracy of SVM algorithm with the new kernel and the hybrid kernel. We test SVM algorithm with our hybrid kernel, the hybrid kernel, Polynomial kernel and RBF kernel. Overall Accuracy and Kappa Coefficient are used to evaluate the quality of the classification image. The result of the experiment shows that the hybrid kernel with the optimal coefficients gives a clearer classification image and has a better accuracy of classification than other algorithms.

9124-35, Session 7

An efficient spatial-spectral classification method for hyperspectral imagery

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It is well-known that including spatial information can improve the classification accuracy of hyperspectral imagery. In this paper, a feature extraction method using a very simple local averaging filter for hyperspectral image classification is proposed. The method potentially smoothes out trivial variations as well as noise of hyperspectral data, and simultaneously exploits the fact that neighboring pixels tend to belong to the same class with high probability. The spectral-spatial features, which are extracted and fed into the designed classifier with locality preserving character in the experimental setup, are compared with other features, such as spectral signature only and wavelet-based spatial features. Simulated results show that the proposed approach facilitates superior discriminant feature extraction and yields significant improvement in hyperspectral image classification performance.

9124-36, Session 7

A stereo remote sensing feature selection method based on artificial bee colony algorithm

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To improve the efficiency of stereo information for remote sensing classification, a stereo remote sensing feature selection method is proposed in this paper presents, which is based on artificial bee colony algorithm.

Remote sensing stereo information could be described DSM and optical image, which contain information of the three-dimensional structure and optical characteristics, respectively. Firstly, three-dimensional structure characteristic could be analyzed by 3D-Zernike descriptors (3DZD). However, different parameters of 3DZD could descript different complexity of three-dimensional structure, and it needs to be better optimized selected for various objects on the ground. Secondly, features for representing optical characteristic also need to be optimized. If not properly handled, when a stereo feature vector composed of 3DZD and image features, that would be a lot of redundant information, and the redundant information may not improve the classification accuracy, even cause adverse effects.

To reduce information redundancy while maintaining or improving the classification accuracy, an optimized model for this stereo feature selection problem is created, and artificial bee colony algorithm is introduced for solving this optimization problem. Experimental results show that the proposed method can effectively improve the computational efficiency, improve the classification accuracy.

9124-37, Session 7

Fisher criterion based nearest feature line approach to land cover classification using multisource data fusion

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In this paper a novel technique, known as nearest feature line (NFL) approach, is proposed for supervised classification of multi-source images for the purpose of landslide hazard assessment. This approach presents a framework for data fusion of multisource remotely sensed images, which consists of two approaches, referred to as band generation process (BGP) and Fisher criterion based NFL classifier. It is developed for land cover classification based on the fusion of remotely sensed images of the same scene collected from multiple sources. Compared to the original NFL, we propose an improve NFL classifier which uses the Fisher criterion of between-class and within-class discrimination to enhance the original one. In the training phase the labeled samples are discriminated by the Fisher criterion, which can be treated as a pre-processing of NFL. The classification results can be obtained by NFL algorithm. In order for the proposed NFL to be effective for multi-spectral images, a multiple adaptation BGP is introduced to create a new set of additional bands especially accommodated to landslide classes. Experimental results demonstrate the proposed BGP/NFL approach is suitable for land cover classification in earth remote sensing and improves the precision of image classification.

9124-38, Session 8

Background suppression issues in anomaly detection for hyperspectral imagery

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Anomaly detection becomes increasingly important in hyperspectral data exploitation due to the use of high spectral resolution which can uncover many unknown substances that cannot be visualized or known a priori. Unfortunately, in real world applications with no availability of ground truth its effectiveness is generally performed by visual inspection which is the only means of evaluating its performance qualitatively in which case background information provides an important piece of information to help image analysts to interpret results of anomaly detection. Interestingly, this issue has never been explored in anomaly detection. This paper investigates the effect of background on anomaly detection via various degrees of background suppression. It decomposes anomaly detection into a two-stage process where the first stage is background suppression so as to enhance anomaly contrast against background and is then followed by a matched filter to increase anomaly detectability by intensity. In order to see background suppression progressively changing with data samples causal anomaly detection is further developed to see how an anomaly detector performs background suppression sample by sample with sample varying spectral correlation. Finally, a 3D ROC analysis used to evaluate effect of background suppression on anomaly detection.

9124-39, Session 8

No-reference remote sensing image quality assessment using a comprehensive evaluation factor

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The conventional image quality assessment algorithm, such as Peak Signal to Noise Ratio (PSNR) Mean Square Error (MSE) and structural similarity (SSIM), needs the original image as a reference. It's not applicable to the remote sensing image for which the original image cannot be assumed to be available. In this paper, a No-reference Image Quality Assessment (NRIQA) algorithm is presented to evaluate the quality of remote sensing image. Since blur and noise (including the stripe noise) are the common distortion factors affecting remote sensing image quality, a comprehensive evaluation factor is modeled to assess the blur and noise by analyzing the image visual properties for different incentives combined with SSIM based on human visual system (HVS) , and also to assess the stripe noise by using Phase Congruency (PC). The experiment results show this algorithm is an accurate and reliable method for Remote Sensing Image Quality Assessment.

9124-40, Session 8

Impact of a revised standard for best practices for academic, governmental and industrial ground station scheduling and communications design

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As launches and satellites lower in overall cost, the variety and purpose of the data collected continues to evolve. This evolution requires a revised set of standards for best practices with regard to academic, governmental and industrial communication and scheduling design. With deliberate consideration into communication and scheduling design, throughput of data passed via the ever more crowded and noisy limited-bandwidth channels can be improved. This study outlines how implementing a revised standard with regard to ground station scheduling and communication impact the expectation for throughput from the satellite itself. For the purposes of the case study under evaluation, two primary focal points are emphasized. First, the off-loading of processing traditionally handled by satellite the satellite itself. Intelligently applying the revised standard for selecting processes to off-load frees up power for transmission and reduces the quantity non-data messaging from the satellite itself. Secondly, revised data format standards have been designed to further decrease non-data transmission as well as improve the delivery of data transmission. Across both of these foci, impacts to error control and correction, image and data processing, and authentication are also examined. The resulting open revised standards for best practices can then be generalized for usage with other satellite and ground station communication.

9124-41, Session 8

An equivalent model for the electromagnetic scattering coefficient of the typical land surface in the microwave band

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A new semi-empirical equivalent model for the different bands and the different polarizations is developed in the microwave band for the soil, concrete, asphalt and the vegetation surface. The Gaussian or the Exponent surface scattering and the possible bulk scattering, the layers reflection scattering are included. The genetic algorithm and the SVR method are used to retrieve the parameters of the equivalent model with the bistatic scattering coefficients of these typical rough surfaces in the L-band and the S-band. After the parameters are determined, the equivalent model can predict the bistatic scattering coefficients of the rough surfaces well in the above bands, which will be very convenient for the numerical computations.

9124-42, Session 8

Unfolding hurricane volume data using focus-plus-context technique

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Volume rendering provides a way to look at volume data. However, user cannot observe the region-of-interest (ROI) because it is obscured. It is also difficult to select ROI using one dimension transfer function. This paper presents a technique to unfold volume data using curved cross section. Our method allows user to select ROI in volume data and project ROI into 2D plane to overcome visual limitations. This approach makes it easy to observe the ROI. Meanwhile, we improve unfolding performance to reach real-time interaction using GPU. In this paper, a case study of hurricane simulation study was conducted to study the time-varying properties. We integrate a region-growing based feature extraction and tracking method into the system to track a feature in the time-varying hurricane simulation volume data. It assists user to unfold the same ROI during observation. The contribution of the proposed system is to generate an unfolding image for time-varying volume data.

9124-43, Session 8

Manifold regularized sparsity model for hyperspectral target detection

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Target detection is one of the most important applications in hyperspectral remote sensing image analysis. Sparse representation method has been considered to be effective in hyperspectral target detection. In this method, a sparse representation with respect to a certain pixel in hyperspectral imagery means a linear combination of few data vectors in the data dictionary. An over complete training dictionary consisting of both target and background samples in the same feature space is first constructed and test pixels are sparsely represented by decomposing over the dictionary. Though sparse representation is considered to preserve main information of most pixels, inevitable indeterminacy may lead to different representations of same or similar pixels. In this paper, a manifold regularized sparse model is proposed to deal with this problem. A graph regularization term is incorporated into the sparsity model under the manifold assumption that similar data pixels should have similar sparse representation. Then a modified simultaneous version of the SP algorithm (SSP) is implemented to obtain the recovered sparse vector which is composed of sparse coefficients corresponding to both target subdictionary and background subdictionary. Once the sparse vector is obtained, the residual between original test samples and estimate recovered from target subdictionary as well as the residual between original test samples and estimate recovered from background subdictionary are calculated to determine the test pixel's class. The proposed algorithm is applied to several hyperspectral imageries to detect targets of interest. Experimental results show a more accurate target detection performance with this proposed model over that with conventional sparse models.