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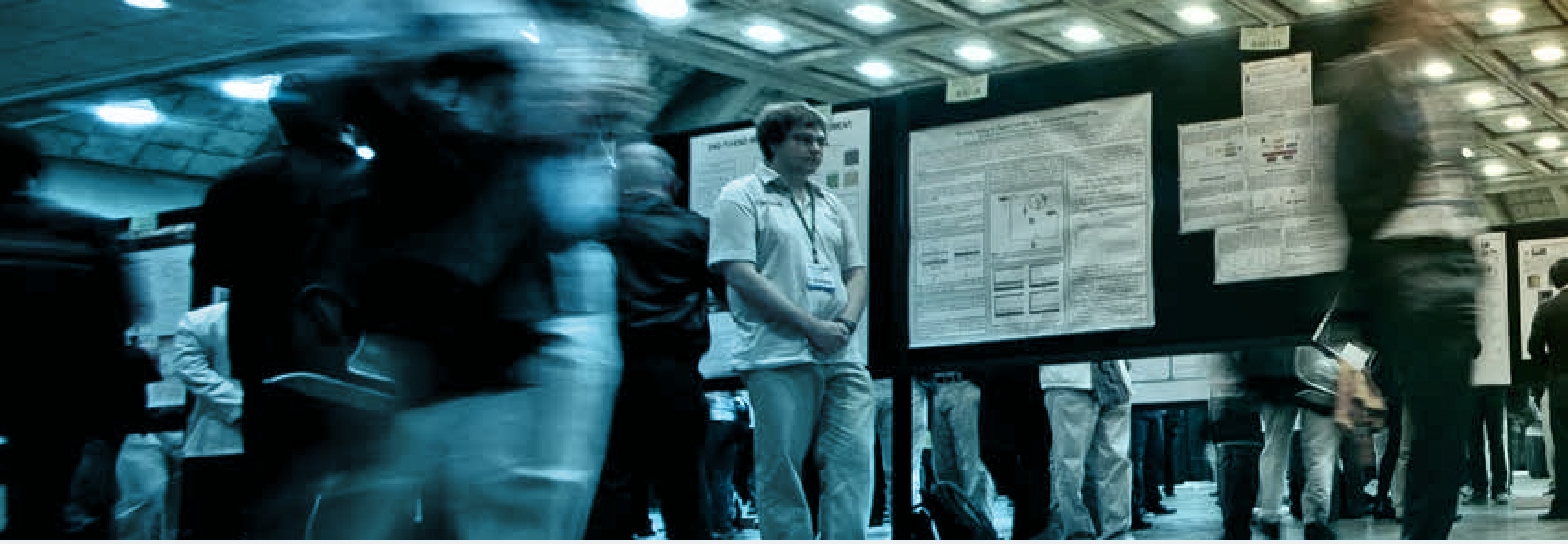

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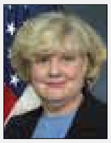

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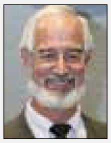

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Conference 9451: Infrared Technology and Applications XLI

Monday - Thursday 20–23 April 2015

Part of Proceedings of SPIE Vol. 9451 Infrared Technology and Applications XLI

9451-1, Session 1

Improved sensitivity performance of SWIR imager in a multispectral VIS/SWIR zoom camera for long-range surveillance tasks

Martin Huebner, Bertram Achtner, Michael Kraus, Mario O. Muenzberg, Airbus DS Optronics GmbH (Germany)

The discussed multispectral sensor suite consists of an HD-TV camera for the visible spectral range and a SWIR camera channel for imaging in combination with an integrated laser range finder all through one common entrance pupil. The sensor suite is deveoloped for long ranging surveillance applications.

A significant reduction of the noise equivalent irradiance (NEI) of the SWIR imager in the multispectral VIS/SWIR sensor suite has been reached by a pitch reduction and corresponding optics F-number reduction of the SWIR channel. The pitch has been reduced from 20μm to 15μm and the F-number from F/7.0 to F/5.25, respectively. The visible channel has an F-number of F/2.6 with an 11- times optical zoom and provides the same field of view and focus position as the SWIR camera with the reduced pitch.

The contributions from the pitch dependent dark current and read out noise levels in combination with the reduced F-number, increasing the resulting signal to noise ratio (SNR), are discussed.

The optical coating designs of the two multispectral beamsplitters for the separation of the visual (450nm – 680nm) from the SWIR spectral wavelength range (900nm – 1700 nm) and the separation of the included laser rangefinder (LRF) receiver channel at 1.57nm center wavelength has been significantly improved in transmission and spectral separation.

First electro-optical results of the improved multispectral sensor suite are discussed and compared with the original design.

9451-2, Session 1

Smart onboard image enhancement algorithms for SWIR day and night vision camera

Jo Das, Koen Vanhoof, Guy Gielis, Benedict Gouverneur, Pieter D. Deroo, Xenics NV (Belgium); Raf L. P. Vandersmissen, sInfraRed Pte. Ltd. (Singapore); Jan P. Vermeiren, Xenics NV (Belgium); Patrick J. Merken, Xenics NV (Belgium) and Royal Military Academy (Belgium)

SWIR imaging based on InGaAs based FPA's is well suited for passive or active day and night vision applications in different weather conditions, including surveillance, defense or fire-fighting. Xenics developed the Rufus camera, based on a 640 x 512 pixel resolution FPA. In order to achieve the best performance over a large span of lighting conditions, different smart algorithms are implemented onboard.

The auto-exposure algorithm optimizes the integration time in order to position the image histogram at a given user-controlled brightness level. Moreover the algorithm can also switch automatically between different gain modes. At the same time a TrueNUC algorithm is calculating the non-uniformity correction. This correction depends on the detector temperature and integration time, because of the variable dark current of the InGaAs diodes. After the image correction and auto-exposure, further image enhancement is done by additional auto-gain and histogram equalization algorithms. Depending on the application, the user can modify several parameters of the algorithms, e.g. the maximal allowed stretching, the output histogram position and equalization strength.

In the paper we will report on the performances of the algorithms at different environmental conditions (up to 70° case temperature). The residual FPN of the TrueNUC model is compared to calibrations optimized for a fixed integration time and detector temperature. For the TrueNUC model a typical residual FPN of <1% is obtained (at 25°C) over the complete integration time range from 100us to 40ms, both in high and low gain. Finally we will illustrate the capabilities of the algorithms in different applications.

9451-3, Session 1

Low-cost SWIR imaging: demonstration of a colloidal quantum dot focal plane array

Ethan J. D. Klem, Christopher W. Gregory, Dorota S. Temple, Jay S. Lewis, RTI International (United States)

RTI has developed a photodiode technology based on solution-processed PbS colloidal quantum dots (CQD). These devices are capable of providing low-cost, high performance detection across the Vis-SWIR spectral range. At the core of this technology is a heterojunction diode structure fabricated using techniques well suited to wafer-scale fabrication, such as spin coating and thermal evaporation. This enables RTI's CQD diodes to be processed at room temperature directly on top of read-out integrated circuits (ROIC), without the need for the hybridization step required by traditional SWIR detectors. Additionally, the CQD diodes can be fabricated on ROICs designed for other detector material systems, effectively allowing rapid prototype demonstrations of CQD focal plane arrays at low cost and on a wide range of pixel pitches and array sizes.

We will show the results of fabricating CQD arrays directly on top of commercially available ROICs. Specifically, the ROICs are a 640 x 512 pixel format with 15 μm pitch, originally developed for InGaAs detectors. We will show that minor modifications to the surface of these ROICs make them suitable for use with our CQD detectors. Once completed, these FPAs are then assembled into a demonstration camera and their imaging performance is evaluated. In addition, we will discuss recent advances in device architecture and processing resulting in devices with room temperature dark currents of 2-5 nA/cm^2 and sensitivity from 350 nm to 1.7 μm.

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.

9451-4, Session 1

InGaAs focal plane array developments and perspectives

Anne Rouvié, Jérôme Coussement, Odile Huet, Jean-Patrick Truffer, Maxime Pozzi, El-Houcine Oubensaid, Sébastien Hamard, Vincent Chaffraix, Eric M. Costard, SOFRADIR (France)

SWIR spectral band is an attractive domain thanks to its intrinsic properties. Close to visible wavelengths, SWIR images interpretation is made easier for field actors. Besides complementary information can be extracted from SWIR band and bring significant added value in several fields of applications such as defense and security (night vision, active imaging), space (earth observation), transport (automotive safety) or industry (non destructive process control).

Among the various new technologies able to detect SWIR wavelengths, InGaAs appears as a key technology. Initially developed for optical telecommunications, this material guaranties performances, stability and reliability and is compatible with attractive production capacity. Thanks to high quality material, very low dark current levels can be achieved at ambient temperature. Then uncooled operation can be set up, allowing compact and low power systems.

Since the recent transfer of InGaAs imaging activities from III-Vlab, Sofradir provides a framework for the production activity with the manufacturing of high performances products: CACTUS320 SW. The developments towards VGA format with 15μm pixel pitch, lead today to the industrialization of a new product: SNAKE. 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 sensor appears as well suited to answer the needs of a wide range of applications.

In this paper, we will present the Sofradir InGaAs technology, the performances of our last product SNAKE and the perspectives of InGaAs new developments.

9451-5, Session 1

Low light level CMOS sensor for night vision camera

Elad Gross, Ran Ginat, Ofer Nesher, Elbit Systems Ltd (Israel)

For many years image intensifier tubes were used for night vision systems.

Elbit developed a low light level CMOS sensor with similar sensitivity to Gen 2 image intensifier, down to starlight illumination conditions.

In this work we describe the basic principle behind this sensor, the physical model, performance and result from field testing.

In addition a theoretical and experimental comparison between other night vision technologies will be shown.

9451-6, Session 1

IR CMOS: the digital nightvision solution to sub-1 mLux imaging

Martin U. Pralle, James E. Carey III, Chris J. Vineis, SiOnyx Inc. (United States)

SiOnyx has demonstrated imaging at light levels below 1 mLux at 60 FPS with a 720P CMOS image sensor in a compact, low latency camera. The camera contains a 1 inch (16 mm) optical format sensor and streams uncompressed video over CameraLink with row wise image latency below 1 msec. Sub mLux imaging is enabled by the combination of enhanced quantum efficiency in the near infrared together with state of the art low noise image sensor design. The quantum efficiency enhancement is achieved by utilizing SiOnyx's proprietary ultrafast laser semiconductor processing technology that enhances the absorption of light within a thin pixel layer. Our 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: daytime imaging out to 2Km

9451-102, Session 1

Extended wavelength SWIR detectors with reduced dark current

Noam Cohen, Ori Aphek, Israel Aerospace Industry (Israel)

Most SWIR sensing applications are limited to cutoff wavelength of 1.7μm at room temperature due to the energy gap of InGaAs alloy lattice matched to InP. Nevertheless, there is an increasing demand for detectors with extended cutoff wavelength of up to 2.5μm for various applications. Due to system requirements those detector should be operated at near room temperature conditions. The high temperature operation requirement limits the use of high Indium content alloys, since those alloys are strained related to the InP substrate and exhibit high dark current and poor uniformity, or even SWIR MCT – both of which need significant cooling.

In this paper we will present some comparative methods for evaluation of extended wavelength SWIR detectors with reduced dark current, working at near room temperature. Those types of detectors can be based on lattice matched alloys consist of type II superlattice, as well as other advanced structures, expected to have better uniformity and utilized for variety of SWIR based applications.

9451-8, Session 2

Semi-scanning single sensor omni-directional observation system *(Invited Paper)*

Yan Itovich, Dan V. Regelman, Rafael Advanced Defense Systems Ltd. (Israel)

A novel omni-directional observation system concept is presented. The observation system resembles a scanning system in the sense that it enjoys high spatial resolution at the expense of temporal resolution. However, the focal plane array (FPA) and objective optics are static, the unique scanning concept ensures no smearing during the exposures and no `dead-time` between the exposures of the individual sectors although the moving parts are all moving continuously at constant angular velocity. The same method enables double-spectral sequential observation without a significant additional complexity to the system. Thus, the suggested observation system is well suited for all application requiring high spatial resolution omni-directional images where the FPA's are expensive and their number of pixels is limited. One important example is SWIR Maritime Situational Awareness (MSA) and Maritime Obstacle Detection (MOD). Implementation of the general concept at SWIR MSA and MOD system suited for Unmanned Surface Vehicle (USV) is discussed.

The system comprised of an inverted multi-faceted pyramidal prism oriented such that each facet reflects an image of a field of view facing it towards the apex of the pyramid. Two discs containing apertures located beneath the apex of the pyramid rotate at the same angular velocity in opposite directions, and an optical arrangement under the disks is arranged to focus light passing through apertures in both disks onto the FPA detector. The apertures in the disks and their angular velocities are adjusted such that apertures in both disks align to allow the image from only one facet at a time to fall on the detector. In one complete revolution of the disks images from all facets fall on the detector; thereby providing a plurality of images that can be combined to form a panoramic view of the surroundings of the system.

9451-10, Session 2

Maritime piracy: design of an infrared multiple cameras system for short-range detection and targeting *(Invited Paper)*

Dominique Maltese, Olivier Reichert, Sagem Défense Sécurité (France)

Naval piracy acts as those that occurred recently in Gulf of Aden near Somalia turn out to be a new threat for commercial ships. Consequently, the implementation of protecting systems to face these acts (soft kill actions) becomes now inevitable and a real challenge. In a near future, commercial ships that are sailing in dangerous areas (straits...) will have to possess more and more dedicated detection and countering capabilities to face coordinated attacks from pirates in different short-range scenarios and environments (open sea, coastal backgrounds...).

In this paper, it is discussed a practical example of a module composed of multiple non-collocated COTS passive sensors and focused on the surveillance of the ship neighboring and its means to detect and track such maritime threats. The surveillance module presented hereafter takes advantage of SAGEM Company experience in naval applications. The paper puts forward the detection process (image processing and 3D tracking). The module is planned to be combined with other ones (radar, electro-optics sensors suites) through a data fusion process to provide the ship with full 3D coverage in its vicinity.

To conclude, results of detection scenarios are provided. Data have been registered during sea trials dedicated to very short range threats. Results highlight how the module detects and tracks the threats. They also put forward how module performances are improved by implementing specific processes such as track fusion.

9451-9, Session 3

Considerations for opto-mechanical versus digital stabilization in surveillance systems *(Invited Paper)*

David Kowal, CONTROP Precision Technologies Ltd. (Israel)

Electro-optical surveillance and reconnaissance systems are frequently mounted on unstable or vibrating platforms such as vehicles, aircraft and masts. Mechanical coupling between the platform and the cameras leads to angular vibration of the line of sight, and a reduction in system performance. Image motion during the detector integration time leads to image smear and a resulting loss of resolution. Additional effects are image smear due to image motion during the integration time of the eye and annoying jumps of the image. A good stabilization system should yield sub-pixel stabilization errors and meet cost and size requirements.

There are two families of LOS stabilization methods: opto-mechanical stabilization and electronic stabilization. Each family, or a combination of both, can be implemented by a number of different techniques of varying complexity, size and cost leading to different levels of stabilization. Opto-mechanial stabilization is typically based on gyro readings, whereas electronic stabilization is typically based on gyro readings or image registration calculations. A few common stabilization techniques as well as options for different gimbal arrangements will be described and analyzed. The relative merits and drawbacks of the different techniques and their applicability to specific systems and environments will be discussed, with an emphasis on systems designed for naval use.

Over the years Controp has developed a large number of stabilized electro-optical payloads. A number of payloads with unique stabilization mechanisms will be described.

9451-11, Session 3

Opportunities and future trends for Navy shipboard imaging systems

James R. Waterman, U.S. Naval Research Lab. (United States)

This paper will examine the potential impact of emerging imaging related technologies on shipboard situational awareness and targeting systems. We will discuss the role of new imaging sensor chips, optical systems, automated detection and classification algorithms, image processing, user interfaces, and display technology in providing leap-ahead capability for imaging in the maritime environment. The challenges associated with that environment and constraints associated with shipboard operation will be considered.

9451-12, Session 4

Future of clip-on weapon sights: pros and cons from an applications perspective

Glen L. Francisco, C. Reed Knight Jr., Ken Greenslade, Knight's Armament Co. (United States)

Clip-On Weapon Sight Technology was deemed an interim solution by the US Government for use until integrated and integrated fused (day/night) Weapon Sights were developed/fielded. Clip-On has become the solution of choice by Users and finally the US Government. Through progressive advances in Clip-On Image Intensified (I2), passive thermal, LL-CMOS and fused I2 &/or LL-CMOS plus thermal capabilities, SWAP-C for weapon sights that are now no longer position sensitive (maintaining aim point boresight) weapon sights are being used at longer ranges, increased capabilities using networked accessible decision making.

Active low-light level (both analog I2 and digital LL-CMOS) imaging is rightfully a real-world technology, proven to bring daytime and low-light level identification confidence. Passive thermal imaging is rightfully a real-world technology, proven to bring daytime, nighttime and all-weather target detection confidence. Image processing detection algorithms with intelligent analytics has provided proven promise to improve confidence by reducing user work-loads and improving overall system engagement solution outcomes. In order to understand the future of clip-on weapon sights, including pros and cons, this paper starts with a brief review of historical weapon sight applications, technologies and stakeholder decisions driving milestone events that helped shape the clip-on weapon history. Then, this paper systematically reviews current attributes of integrated multispectral wavelength electro-optical imaging systems that are being successfully (and unsuccessfully) used to shape today's User's net-capabilities. Finally, this paper will explore the pros and cons of future clip-on weapon sights for tomorrow's military solider and paramilitary first responder, from a real world applications perspective.

9451-13, Session 4

Development of an infrared ultra-compact multichannel camera integrated in a SOFRADIR's detector Dewar cooler assembly

Florence de la Barrière, Guillaume Druart, Nicolas Guérineau, Aurélien Plyer, ONERA (France); Gilles Lasfargues, Eric D. de Borniol, Commissariat à l'Énergie Atomique (France); Serge Magli, SOFRADIR (France)

We present a prototype of an infrared cryogenic camera directly integrated inside an off-the-shelf SOFRADIR's Detector Dewar Cooler Assembly and whose field of view is equal to 120°. Based on the co-design principle

between optical design and image processing, we have designed a multichannel lens that produces four non-redundant images on a single SCORPIO detector of format 640x512 and with a pixel pitch of 15μm. This leads to an ultra-miniaturized optical system with a greatly decrease of the additional optical and mechanical mass to be cooled. By this way, the cool-down time of the camera is comparable to the one of an equivalent DDCA without an imagery function. With a superresolution algorithm, the four images produced by the camera are combined to restitute a single full-resolution image with an equivalent sampling pitch equal to 7.5μm. The performances of this camera will be presented with experimental characterizations and, finally, the adaptation of this camera to a Daphnis detector with a format of 1280x720 and a pixel pitch of 10μm will be discussed.

9451-14, Session 4

Spin scan tomographic infrared imager

Harald Hovland, Norwegian Defence Research Establishment (Norway)

A novel imaging device based on tomographic reconstruction is presented. The imager is based on rotating an image of the scene onto a linear detector array, and then reconstructiong a 2-dimensional image from the detector array signal using tomographic reconstruction techniques. Similar in many ways to the conical scan tomographic scanning (TOSCA) imager, the spin scan TOSCA imager features several improvements compared to its predecessors, mainly because the linear array covers the whole scene and hence in principle can collect 100% of the incoming photons. In addition to presenting the theory behind the device and its sensitivity to noise, nonuniformity and errors, an experimental uncooled mid-wave infrared imager demonstrator is also presented, together with images and videos of test targets, both the final result as well as the incremental steps in the imaging reconstruction process.

9451-16, Session 5

Minimising blooming in MWIR missile launch systems

Patrick R. Body, TECNOBIT (Spain)

Due to the enormous differences in the radiance between standard scenes and the missile plume, MWIR missile launch systems have always suffered from launch blindness due to blooming. Although most IR detector manufacturers now include anti-blooming functions this does not solve the problem of large scale image saturation at the integration times required to clearly see the rest of the scene including the targets. This paper presents a low latency technique that has been developed to minimise this effect which allows an ACLOS system to maintain sight of the target and the missile body simultaneously permitting it to take control of wire guided missiles within the first few seconds of flight.

The presentation explains the physics behind the causes of the blooming and includes images and videos showing the effects using traditional systems. These are then contrasted with images and videos showing the effect of the anti-blooming process on the MWIR images. Also shown are LWIR images of the same scene as a control since LWIR detectors do not traditionally suffer from this problem.

Standard MWIR detectors and optics are used at all times so the process can be adapted to existing systems without any major redesign being necessary.

Although specifically developed to overcome launch blindness, the technique can also be used to increase system sensitivity in high contrast scenes such as above and below the horizon increasing system performance and detectivity ranges. Images and videos of this application are also shown.

9451-17, Session 5

Passive electro optical counter-countermeasures

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

Today's modern warfare relies heavily on optical sensors for information gathering. Optical equipment is used by the military personal for many purposes, e.g. observation, navigation, fire control, and reconnaissance. The laser, on the other hand, is a powerful countermeasure against optical equipment, particularly the detectors and is used to disable optical sensors, including the human eye when using direct vision, e.g. through a sight, exposed to damaging laser light. Protection of the sensors and human eyes has to be developed and fielded widely.

With the development of more powerful lasers for military applications, optical limiters and blockers are required for providing human eye and optical sensors protection. 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. A common option is to use a notch filter to remove a narrow band of wavelengths. However, these types of filters block power at a specific wavelength regardless of the power level and versatility of the damaging laser. The availability of wavelength agile lasers makes this strategy useless. The major drawbacks of this solution are that the color impression may be affected and that the protection is limited to specific wavelengths only, whereas the threats can exist in any other laser wavelengths. Smart protection is needed, a filter that is transparent for low input intensities and limit or block the high input intensities, and is effective over a wide band of wavelengths.

In a 2003 publication by the US National research council, named "Materials research to meet the 21th century defense needs"(Ref1) the following is stated: "Optical Limiting Materials: Progress in compact laser systems made laser weapons possible, but it is a challenging task to protect sensors and eyes from laser light damage because there is a wide range of laser systems with different temporal and spectral characteristics".

This was an invitation to develop electro-optic counter-countermeasure EOCCM to mitigate the damage that can be inflected on optical and electrooptical sights, thus maintaining its operational value. As laser countermeasures proliferate around the world, infantry, aircrews and electro-optic sensors are at risk of being engaged with little to no warning. A laser countermeasure can adversely affect targeting and navigation functions by jamming or 'spoofing' the sensor through laser illumination (transient performance degradation) or by damaging the sensor through more intense laser illumination (permanent performance degradation). The laser can also be used to detect and track an otherwise covert electro-optic target by sensing retro-reflections off the target optics.

KiloLambda technologies took this challenge as a goal and developed a family of passive, nanotechnology based, protection filters for continuous and pulsed lasers that are effective in a very wide spectral region using a single filter, thus hardening optical sights on various platforms. This paper presents a non-linear, solid-state passive wideband optical protection filters (WPF). These filters have advantages over fixed spectral filters, which permanently block only specific wavelengths, the wideband filter is transparent at all wavelengths until it is hit by damaging light. We present work in continuation of our special design WPF suitable for dual-band wavelength range, which protects in the near as well as in the mid IR from laser threats.

9451-18, Session 5

Daylight coloring for monochrome infrared imagery

James Gabura, Raytheon ELCAN Optical Technologies (Canada)

Is it possible to create daylight colored imagery from a monochrome infrared sensor? Under difficult seeing conditions it may be hard to generate a useful image in the visible light range. Even if a visible light image is generated under such circumstances it is often low in contrast. By distinction, infrared imagery is very useful for enhancing night visibility or for penetrating fog and smoke. Previous approaches to colorizing nighttime imagery have utilized either an intensified visible-light imager where the luminances of the source are similar to those in the colorized image, or a multispectral imager where intensity combinations in multiple wavebands outside of the visible spectrum can be transformed via a color table into realistic RGB color values. By contrast, our method works with a monochromatic single-band infrared source image typically exhibiting a luminance scale that is uncorrelated with its corresponding natural daylight colorized version. The method starts with two reference images, one infrared and one color, of a similar but different scene from the one to be colorized. The two reference images are of the same size, and are registered pixel by pixel. From these, a 2D color table is generated in which RGB values from pixels of the color image are indexed by the mean and standard deviation from a region around the pixels of the corresponding infrared image. The only information derived from the source scene and utilized in the transformation is the monochrome source image. We present our algorithm for colorizing infrared images with examples.

9451-20, Session 6

Type-II superlattice detector for long-wave infrared imaging *(Invited Paper)*

Philip C. Klipstein, Eran Avnon, Yael Benny, Avraham Fraenkel, Alex Glozman, Elad Ilan, Ezra Kahanov, Olga Klin, Lidia Langof, SCD SemiConductor Devices (Israel); Yoav Livneh, Israel Ministry of Defense (Israel); Inna Lukomsky, Michal Nitzani, Lior Shkedy, Itay Shtrichman, Noam Snapi, Ron Talmor, SCD SemiConductor Devices (Israel); Avi Tuito, IMOD (Israel); Shay Vaserman, Eliezer Weiss, SCD SemiConductor Devices (Israel)

Type II InAs/GaSb superlattices (T2SLs) are a promising III-V alternative to HgCdTe for infrared Focal Plane Array (FPA) detectors. They offer full wavelength tunability through the Mid Wave and Long Wave infrared atmospheric windows. When incorporated into an “XBp” barrier detector structure they also offer diffusion limited dark currents which are within one order of magnitude of those found in state of the art Mercury Cadmium Telluride (according to MCT Rule 07). High quantum efficiencies can also be achieved with a relatively thin stack thickness for the absorbing layer. A key to the successful engineering of such structures is the use of suitable simulation software that can determine the band alignments and detector quantum efficiency as a function of the period dimensions and stack thickness. Using this approach we have developed an XBp T2SL FPA detector with a format of 640x512 and 15 micron pitch. The detector has a high quantum efficiency with a cut-off wavelength of ~9.5 micron, and operates at 77K with background limited performance (BLIP). The BLIP temperature at F/2 is ~100K (photo-current = dark current). The digital Read-Out Integrated Circuit (ROIC) closely follows the configuration of SCD’s Pelican-D detector, and its Interface Control Document (ICD) is fully compatible with Pelican-D. The measured NETD is 15mK at F/2, for a blackbody temperature of 25 C and a frame rate of 30Hz. The design principles and radiometric performance of the detector will be presented, and illustrated with examples of image quality.

9451-21, Session 6

InAs/Ga(In)Sb type-II superlattices short/middle dual-color infrared detectors *(Invited Paper)*

Yanli Shi, Kunming Institute of Physics (China)

Short wavelength and middle wavelength dual color infrared detector were designed and prepared with InAs/Ga(In)Sb type-II superlattices materials. The Crosslight software was used to calculate the relation between wavelength and material parameter such as thickness of InAs?GaSb, then energy strucutre of 100 periods 8ML/8ML InAs/GaSb and the absorption wavelength was calculated. After fixing InAs/GaSb thickness parameter, devices with nBn and pin structure were designed and prepared to compare performance of these two structures. Comparison results showed both structure devices were available for high temperature operation which black detectivity under 200K were 7.9?108cmHz1/2/W for nBn and 1.9?109cmHz1/2/W for pin respectively. Considering the simultaneous readout requirement for further FPAs application the NIP/PIN InAs/GaSb dual-color structure was grown by MBE method. Both two mesas and one mesa devices structure were designed and prepared to appreciate the short/middle dual color devices. Cl2-based ICP etching combined with phosphoric acid based chemicals were utilized to form mesas, silicon dioxide was deposited via PECVD as passivation layer. Ti/Au was used as metallization. Once the devices were finished, the electro-optical performance was measured. Measurement results showed that optical spectrum response with peak wavelength of 2.7?m and 4.3?m under 77K temperature was gained, the test results agree well with calculated results. Peak detectivity was measured as 2.08?1011cmHz1/2/W and 6.2?1010cmHz1/2/W for short and middle wavelength infrared detector respectively. Study results disclosed that InAs/Ga(In)Sb type-II SLs is available for both short and middle wavelength infrared detecting with good performance by simply altering the thickness of InAs layer and GaSb layer.

9451-103, Session 6

Optimization of Type-II superlattice heterojunction infrared detectors *(Invited Paper)*

Sumith Bandara, Neil Baril, Patrick G. Maloney, Curtis Billman, Nathan Henry, Alexander Brown, Eric Nallon, Joseph G. Pellegrino, Meimei Tidrow, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Design parameters for the heterojunction-based strained layer superlattice (SLS) long-wave infrared (LWIR) detector are investigated so that it operates at a lower bias voltage with lower dark current and higher photo response. At typical operating temperatures (T~77 K), the dark current of GaSb/InAs SLS LWIR detectors is dominated by the Shockley-Read-Hall (SRH) generation-recombination (g-r) process in the space-charge (depletion) region. In order to suppress this dark current, a wide bandgap region next to the absorber layer has been included in recent SLS designs. A series of heterojunction-based LWIR SLS detectors with various doping and barrier profiles have been designed and characterized. The significance of the doping profile and thickness of the wide-bandgap layer in optimization of the heterojunction-based SLS detector performance are exhibited from the modeling and experimental results of these devices.

9451-22, Session 7

Current directions in sensor technologies at NVESD *(Keynote Presentation)*

Donald Reago, U.S. Army RDECOM CERDEC NVESD (United States)

No Abstract Available

9451-24, Session 8

Limiting dark current mechanisms in antimony-based superlattice infrared detectors for the mid- and long-wavelength infrared regime

Robert Rehm, Volker Daumer, Tsvetlina Hugger, Norbert Kohn, Florian Lemke, Wolfgang Luppold, Jasmin Niemasz, Johannes Schmidt, Johannes Schmitz, Frank Rutz, Tim O. Stadelmann, Matthias Wauro, Andreas Wörl, Martin Walther, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany)

Within the last decade type-II superlattice (T2SL) infrared (IR) detector technology for the mid- (3 5 μm, MWIR) and long-wavelength (8-12 μm, LWIR) transmission window of the atmosphere has progressed from lab demonstration to first commercial applications. To further increase the electro-optical performance of today's T2SL detectors, the development focus is currently on the reduction of the detector dark current. Correct identification of the limiting current mechanisms and extraction of the corresponding material and device parameters are key to improve both the manufacturing technology and the device design. Certainly, the separation of bulk and sidewall contributions is indispensable to avoid misconceptions.

In this paper, we will present a temperature-dependent investigation of the limiting dark current mechanisms in several homojunction InAs/GaSb SL photodiode wafers grown in two different molecular beam epitaxy (MBE) reactors. Subtraction of the measured sidewall contribution allows us to fit sophisticated models from the literature to the bulk dark current and extract bulk parameters like, e.g., background doping, shunt resistance, trap density and carrier lifetimes. The results from both MBE reactors will be evaluated and we will compare our findings to the available literature.

9451-25, Session 8

Modeling of the InAs/GaSb superlattices performance

Julien Imbert, ONERA (France); Virginie Trinite, III-V Lab. (France); Sophie Derelle, Julien Jaeck, ONERA (France); Jean-Baptiste Rodriguez, Institut d'Electronique du Sud (France); Riad Haidar, ONERA (France); Mathieu Carras, III-V Lab. (France); Philippe Christol, Institut d'Electronique du Sud (France)

A 18-band k.p formalism has been developed to determine the band structure and wave functions of InAs/GaSb type II superlattices (T2SL). First bandgap results are in good agreement with bandgaps measured for symetrical superlattices. In order to validate the input parameters of our model, we developed a tool to simulate the absorption coefficient and compare results with measurements performed on superlattice samples at cryogenic temperature. Thus we are able to calculate theoretical optical and electrical properties of InAs/GaSb T2SL as the effective mass, the absorption coefficient and the free carrier concentration.

The IES team manufactures different T2SL structures with a different InAs to GaSb thickness ratio R, but the same cut-off wavelength of 5μm at 77K. We compare these properties for these structures in order to investigate the influence of this ratio R. This model allows to unravel the well-known 2D/3D behaviours of the InAs-rich and GaSb-rich asymmetric SL structures.

Our main objective is to simulate the transport and then to predict the complete performance of a T2SL detector. The next step of our work is to have a good agreement on the absorption spectra between measurements performed on specific T2SL samples and modeling.

Once the model confirmed by this comparison, we will be able to give reliable datas for intrinsic parameters of T2SL. we will then work on the transport of a T2SL detector, using the intrinsic parameters previously calculated, and will be able to describe the complete performance of a T2SL detector. We will then influence the new designs of structure of T2SL that will be more efficient.

9451-26, Session 8

Carrier transport in unipolar barrier infrared detectors

David Z. Ting, Alexander Soibel, Linda Höglund, Cory J. Hill, Arezou Khoshakhlagh, Sam A. Keo, Anita M. Fisher, Layton Baker, Edward M. Luong, Robert S. Kowalczyk, John K. Liu, Jason M. Mumolo, Sir B. Rafol, Sarath D. Gunapala, Jet Propulsion Lab. (United States)

We examine carrier transport in unipolar barrier infrared photodetectors such as the nBn detector and the complementary barrier infrared detector (CBIRD). In a barrier infrared detector the unipolar barrier should block only the majority carriers while allowing the un-impeded flow of the minority carriers. Under the right conditions, unipolar barrier doping can reduce generation-recombination dark current without affecting minority carrier extraction. However, improper barrier doping or barrier-absorber band offset could also block minority carriers and result in higher turn-on bias, as has been observed in both MWIR and LWIR devices. Contact doping has also been observed to result in temperature-dependent turn-on bias. Hole mobility in n-doped type-II superlattice (T2SL) is believed to be very low because of the extremely large effective mass along the growth direction. In practice MWIR and LWIR barrier infrared detectors with n-type T2SL absorbers have demonstrated good optical response. A closer inspection of the T2SL band structure offers a possible explanation as to why the hole mobility may not be as poor as suggested by the simple effective mass picture.

9451-27, Session 8

Minority carrier lifetimes in InAs/InAsSb type-II superlattices measured using double-modulation time-resolved photoluminescence

Zhiyuan Lin, Shi Liu, Yong-Hang Zhang, Arizona State Univ. (United States)

Ga-free InAs/InAsSb type II superlattice (T2SL) has attracted much attention due to its potential as an alternative material to HgCdTe for infrared detectors. Recently the minority carrier lifetimes of InAs/InAsSb T2SLs have been improved to the order of μs, which is two orders of magnitudes longer than that of the InAs/(In)GaSb T2SLs. However the temperature dependence of the minority carrier lifetime is not well understood yet. In this study, the minority carrier lifetimes of a series of InAs/InAsSb T2SLs grown by molecular beam epitaxy (MBE) are measured by a time-resolved photoluminescence (TRPL) system using a double-modulation technique, which has been demonstrated to significantly improve the signal-to-noise ratio of the measurements. The technique modulates the excitation pulse laser using a low frequency chopper and collecting the signal using a lock-in amplifier. The longest minority carrier lifetime of a mid-wavelength infrared InAs/InAsSb T2SL is measured to be 2.8 μs at 12 K, longer than that (1.24 ?s) of an MBE-grown InAs0.91Sb0.09 sample with similar structure. The lifetime of the T2SL gradually decreases to 0.71 μs when temperature ramps up to 77 K, and then increases to 0.8 μs with the temperature increasing to 120 K. Thereafter the lifetime keeps decreasing as the temperature ramps up to 300 K. Excitation dependent PL measurements are carried out and show that Shockley-Reed-Hall recombination contributes significantly to the minority carrier lifetimes from 12K to 150K. Details of the TRPL measurements and the physical interpretation of the temperature-dependent behavior of the minority carrier lifetime of the T2SL will be presented at the conference.

9451-29, Session 8

Confocal Raman Spectroscopy and AFM for Evaluation of Sidewalls in Type II Superlattices

Alexander A. Ukhanov, Tito L. Busani, Pranav Rathi, Thomas J. Rotter, Felix Jaeckel, Kevin J. Malloy, Actoprobe LLC (United States); Elena Plis, Sanjay Krishna, SKINfrared LLC (United States); Neil F. Baril, J. D. Benson, Marvin Jaime-Vasquez, U.S. Army RDECOM CERDEC NVESD (United States); Dmitri A. Tenne, Boise State Univ. (United States)

Long-wave (LW) and multicolor infrared (IR) detectors are desirable in a variety of applications related to remote sensing and object identification. Detectors based on mercury cadmium telluride (MCT) and quantum well infrared detectors (QWIPs) have been the dominant technologies for such applications. InAs/GaSb type-II strained layer superlattice (T2SL) detectors are predicted to have a number of advantages over MCT devices, including lower tunneling currents, suppressed Auger recombination, and an improved bandgap uniformity over large areas. By optimizing the oscillator strength in T2SL, a large quantum efficiency may be obtained that overcome the inherent problem of QWIP detectors. Moreover, the commercial availability of substrates with good electro-optical homogeneity, and without large cluster defects, also offers advantages for T2SL technology.

However, due to complexity of InAs/GaSb system, etch and passivation of T2SL detectors is still an issue especially, in the LWIR spectral range. We propose to utilize confocal Raman spectroscopy combined with the high resolution AFM technique, to access the sidewall profiles of etch and passivated small (24μm x 24μm) focal plane array (FPA) features fabricated using LW/LWIR T2SL detector material. Special high aspect ratio Si and GaAs AFM probes, with tip length of 13μm and tip aperture less than 7 degrees, allow imaging of sidewall profile through optical sectioning. Raman spectra measured on etched T2SL FPA single pixels enable us to quantify the non-uniformity of the mesa delineation process. More experimental details on non-destructive characterization of T2SL FPAs will be discussed during the presentation.

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9451-30, Session 8

Growth and characterization of ≥6" epitaxy-ready GaSb substrates for use in large area infrared detector applications

Mark J. Furlong, IQE IR (United Kingdom); Rebecca J. Martinez, Marius Tybjerg, Andrew Mowbray, Brian Smith, Wafer Technology Ltd. (United Kingdom)

In this paper we report on an industry first; the commercial growth and characterization of >/=6" diameter GaSb substrates that are suitable for use in the fabrication of epitaxially grown, large area MWIR-VLWIR detectors. Results will be presented on the production of single crystal >/=6" GaSb ingots grown by a modified version of the Czochralski (LEC) technique, supported by the analysis of bulk material quality by spatial etch pit density assessments with mm resolution. The electrical quality of 6" GaSb crystals will be assessed. Hall mobility, resistivity and carrier level measurements will be made spatially. IR transmission spectra of ultra-low doped 6" substrates will be presented demonstrating the suitability of this material for VLWIR devices. High quality, epitaxy-ready type surfaces have been prepared and we will demonstrate how the key surface quality characteristics of roughness, oxide thickness and flatness have been maintained across production processes that scale 4" to ≥6" wafer formats. Comparisons will be made between ≥6" GaSb and other large diameter compound semiconductor materials produced in volume such as GaAs and InP. We conclude by demonstrating that the commercial production of large diameter GaSb substrates has matured and is thus ready to support the full commercialization of GaSb based detector technologies.

9451-31, Session 8

MBE growth of Sb-based bulk nBn infrared photodetector structures on ≥6" GaSb substrates

Amy W. K. Liu, Dmitri Loubychev, Yueming Qiu, Joel M. Fastenau, IQE Inc. (United States); Mark J. Furlong, IQE IR (United Kingdom); Marius Tybjerg, Wafer Technology Ltd. (United Kingdom); Rebecca J. Martinez, IQE IR (United Kingdom); Andrew Mowbray, Brian Smith, Wafer Technology Ltd. (United Kingdom)

The GaSb-based 6.1 Å lattice constant family of materials and heterostructures provides rich bandgap engineering possibilities and have received considerable attention for their potential and demonstrated performance in infrared (IR) detection and imaging applications. Mid-wave and long-wave IR photodetectors are progressing toward commercial manufacturing applications. To succeed, they must move from research laboratory settings to general semiconductor production, and high-quality GaSb-based epitaxial wafers with diameter larger than the current standard 3-inch are highly desirable. 4 inch GaSb substrates have been in production for a couple of years and are now commercially available. Recently, epi-ready GaSb substrates with diameter in excess of 6 inch were successfully produced.

In this work, we report on the MBE (Molecular Beam Epitaxy) growth of generic MWIR bulk nBn photodetectors on ≥6 inch diameter GaSb substrates. The surface morphology, optical and structural quality of the epiwafers as evaluated by atomic force microscopy (AFM), Nomarski microscopy, low temperature photoluminescence (PL) spectroscopy, and high-resolution x-ray diffraction (XRD) will be discussed. IV measurements from large-area mesa diode fabricated will also be reported. Material and device properties of these ≥6 inch epiwafers will be compared to similar structures grown on 4-inch diameter GaSb, as well as metamorphically on 6-inch GaAs substrates.

9451-32, Session 9

Digital pixel readout integrated circuit architectures for LWIR

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

This paper presents and discusses digital pixel readout integrated circuit architectures for long wavelength infrared in CMOS technology. Presented architectures are designed for respectively scanning and staring arrays. For scanning arrays, digital time delay integration (TDI) is implemented on 8 pixels with over sampling rate of 3 in CMOS 180nm technology. For staring type arrays, A digital ROIC with extending counting method architecture is presented. It achieves very low quantization noise (161 electrons) while having a very high (2.33Ge-) charge handling capacity in CMOS 90nm technology.

In the digital scanning architecture, 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. Quantization noise of analog-to-digital conversion is less than 500e-. ROIC is fabricated with 0.18?m CMOS process. Post-layout simulation results of the implemented design are presented.

Current state of the art has shown that staring digital readouts with pulse frequency method can achieve charge handling capacities higher than

3Ge- with quantization noise higher than 1000e-. Even if the integration capacitance is reduced, it cannot be lower than 1-3 fF due to the parasitic capacitance of the comparator. For achieving a very low quantization noise of 161 electrons in a power efficient way, a new method based on measuring the time to measure the remaining charge on the integration capacitor is proposed. With this approach SNR of low flux pixels are significantly increased while large flux pixels can store electrons as high as 2.33Ge-.

9451-33, Session 9

A 1280x1024-15μm CTIA ROIC for SWIR FPAs

Selim Eminoglu, MikroSens Elektronik San ve Tic A S (Turkey)

No Abstract Available

9451-34, Session 9

Cryogenic measurements of a digital pixel readout integrated circuit for LWIR

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

This paper presents and discusses the cryogenic temperature (77K) measurement results of a digital readout integrated circuit based on pulse frequency modulation (PFM) technique for a 32x32 long wavelength infrared pixel sensor array designed in 90nm CMOS process. The chip achieves a SNR of 58dB with a charge handling capacity of 2.03Ge- at cryogenic temperature with 1.3mW of power dissipation. The performance of the readout is discussed in terms of power dissipation, charge handling capacity and SNR considering the fact that the process library models are not optimized for cryogenic temperature operation of the MOS devices. These results provide an insight to foresee the design confrontations due to non-optimized devices model for cryogenic temperatures particularly for short channel devices.

In the same chip, several NMOS and PMOS standalone test devices are placed to measure their current-voltage (I-V) curves at 300K and cryogenic temperature to determine the deviation from their spice model simulations at 77K. There are three different sets of device sizes Width/Length (W/L) 10um/10um, 600nm/100nm, and 120nm/100nm, for both NMOS and PMOS. These device aspects ratios are selected based upon minimum W/L, intermediate and the maximum W/L of transistors which have been used in actual design of DROIC, and to analyze the difference of temperature variations on small and long channel length devices.

9451-7, Session PTue

Design of IR omni-directional optical system for night vision and surveillance of defence and safety

Jae Heung Jo, Hannam Univ. (Korea, Republic of); Jae Myung Ryu, Kumoh National Institute of Technology (Korea, Republic of); Jong-goo Kang, Hannam Univ. (Korea, Republic of)

The omni-directional optical system designed with a catadioptric system in this paper. So this omni-directional system has the primary and second mirror where the primary mirror has a convex surface, and the second mirror is plane. We must decide diameter of the primary mirror and obscuration, the position of mirrors, the incident angle of chief ray at rear imaging system and so on in order to design the omni-directional optical system. We confirm this paraxial design method that can be applied to the infrared (IR) omni-directional optical system.

9451-74, Session PTue

Dark current characterization of very long-wavelength HgCdTe photodetectors

Weida Hu, Xiaoshuang Chen, Shanghai Institute of Technical Physics (China)

Detection in the very long wave infrared range (LWIR, 12-15μm) using third-generation infrared focal plane array (FPAs) is essential for remote atmosphere sounding. Indeed, these wavelengths are particularly rich in information about humidity and CO2 levels and provide additional information about cloud structure and temperature profile across the atmosphere. However, the dark current characteristic and associated noise behavior of the HgCdTe photodiode in the wavelength range of 12-15μm, operating at ~77K, are very sensitive to surface passivation techniques as well as to surface material treatments. For current HgCdTe material and device technology, detection of LWIR and VLWIR energy is the subject of current research. Within this range of shrinking band-gaps in detector material, precise control of the quality of the surface passivation and treatment is of great importance. The underlying physics of dark current mechanism is theoretically investigated by using a previously developed simultaneous current extraction approach and numerical simulations.

9451-76, Session PTue

Stress effects on electrical transportation properties of HgCdTe film

Pengyun Song, Xing Chen, Shan Zhang, Shanghai Institute of Technical Physics (China); Zhenhua Ye, Shanghai Institute of Technical Physics (China); Xiaoning Hu, Shanghai Institute of Technical Physics (China)

It has been demonstrated that stress state of HgCdTe layers has significant effects on the electrical properties of HgCdTe film and thus the performance of hybrid infrared focal plane array detectors based on HgCdTe materials because of thermal expansion mismatch at low temperature arising from its multilayer structure. In order to further study the stress effect, a piece of Hg vacancis doped p-type square HgCdTe grown on Si substrate using MBE method is selected and various states of stress is introduced into the HgCdTe film through sticking various thickness of covar layer to the backside of the Si substrate. Using infinite elements analysis the stress state and deformation of the sample could be determined accordingly at low temperature. The surface of the sample is initially capped by as-grown CdTe layer which is thereafter corroded by wet chemical method in order to avoid the disturbation of the surface layer. The Hall measurement of the sample with different stress states is performed with magnetic field and temperature ranging from -1.5 to 1.5 Tesla and from 20 K to 300 K respectively using Van de Pauw method in order to obtain the carrier density and mobility after it is passivated by doule layers of CdTe and ZnS with thickness of 1000 and 2300 angstroms respectively. PL spectrum measurement is used to obtain energy band gap of the sample at low temperature. The experiment results show that the electrical transportation properties of HgCdTe film could vary along with the change of the stress state and possible mechanism underlying is presented.

9451-91, Session PTue

Study on magnetic circuit of moving magnet linear compressor

Xia Ming, Xiaoping Chen, Jun Chen, Kunming Institute of Physics (China)

The moving magnet linear compressors are very popular in the tactical miniature stirling cryocoolers. The magnetic circuit of LFC3600 moving magnet linear compressor, manufactured by Kunming institute of Physics,

was studied in this study. The analysis theory, numerical calculation and experiment study were investigated in the analysis process. The calculated formula of magnetic reluctance and magnetomotive force were given in theoretical analysis model. The magnetic flux density and magnetic flux line were analyzed in numerical analysis model. A testing method was designed to test the magnetic flux density of the linear compressor. When the piston of the motor was in the equilibrium position, the value of the magnetic flux density was at the maximum of 0.27T. The results were almost equal to the ones(0.29T) from numerical analysis.

9451-92, Session PTue

Polarization-selective uncooled infrared sensor using a one-dimensional plasmonic grating absorber

Shinpei Ogawa, Mitsubishi Electric Corp. (Japan); Yousuke Takagawa, Masafumi Kimata, Ritsumeikan Univ. (Japan)

Information such as the shape, position and average radiant intensity of objects can be observed using a typical uncooled infrared (IR) sensor; however, polarization information cannot be obtained with such a sensor. Artificial objects, such as vehicles, buildings, roads and agricultural fields, change the polarization state of the electromagnetic field reflected or emitted from their surfaces. Therefore, human influences can be distinguished from the natural environment on the Earth by polarimetric sensing. A polarization-selective uncooled IR sensor has been developed using a one-dimensional plasmonic grating absorber (1D-PGA). The 1D-PGA has an Au-based one-dimensional periodic grating structure, where photons can be manipulated by surface plasmon polaritons. Numerical investigations demonstrate that 1D-PGA gives rise to polarization-dependent absorption properties according to the grating direction. The absorption wavelength can be defined by such parameters as the depth and the width in addition to the grating period. A microelectromechanical systems-based uncooled IR sensor was fabricated using PGA through a complementary metal oxide semiconductor (CMOS) and micromachining techniques. The 1D-PGA was formed by an Au layer sputtered on a SiO2 layer with one-dimensional periodic grating. An Al layer was then introduced on the backside of the 1D-PGA to reflect scattered light and prevent absorption at the SiO2 substrate. Measurement of the responsivity dependence on the polarization shows that the responsivity is selectively enhanced depending on the polarization and the direction of the gratings. The results provide direct evidence that a polarization-selective uncooled IR sensor can be realized simply by using 1D-PGA without any polarizer or optical resonant structures. In addition, a pixel array where each pixel has a different detection polarization could be developed for polarimetric imaging using standard CMOS and micromachining techniques.

9451-93, Session PTue

Model, design, and fabrication of antenna coupled metal-insulator-metal diodes for IR sensing

Mesut Inac, Atia Shafique, Meriç Özcan, Sabanci Univ. (Turkey); Yasar Gurbuz, Sabanci University (Turkey)

Demand for the inexpensive devices operating at room temperature for infrared (IR) sensing and imaging are increasing in the last years. Due to the small sizes and the integration capabilities, antenna coupled metal-insulator-metal (MIM) diodes are one of the potential candidates in the field of IR sensing and imaging. The antenna coupled diodes are already illustrated in the literature for energy harvesting applications and wireless power transmission. The miniaturizing feature and ease of integration with infrared focal plane array makes antenna-coupled-MIM diode an attractive alternative for IR sensing and imaging applications. As matter of fact, MIM diode's functionality based on quantum tunneling leads to device time constant as lower as few femtoseconds. The smaller sizes of these devices can enable more pixels in detectors. In general, conventional IR detectors are classified based on two mechanisms: thermal detectors and photon detectors. Due to the inevitable limitations of the both types, antenna-coupled diode is thought to be a better choice as an ultra-fast and highly responsive IR detector.

In this work, it is aimed to design and develop a device that can act as IR detector at room temperature. The model formation is based on electron tunneling in MIM diode devices. First the preliminary DC characterization of individual MIM diodes have been carried out, afterwards, joint characterization of antenna along with diode has been performed. Device characteristics such as responsivity, I-V and C-V results are reported.

9451-94, Session PTue

Low-power LVDS for digital readout circuits

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

This paper presents information about the design of a mixed-signal LVDS driver in 90 nm CMOS technology. The designed LVDS core is to be used as a data link between Infrared Focal Plane Array (IRFPA) detector end and microprocessor input. Parallel data from 220 pixels of IRFPA is serialized by LVDS driver and read out to microprocessor. It also offers a reduced power consumption rate, high data transmission speed and utilizes dense placement of devices for area efficiency. Due to those features, the designed LVDS driver is suitable for purposes such as portable, high-speed imaging. Additionally, the design offers a wide range of temperature of operation. It can provide fast data transmission at room temperature and within cryogenic temperature range.

Switchable current source LVDS core consists of two PMOS current sources turning on and off with respect to input pulse. Changing polarity of the current flowing on the differential load creates voltage swing. Differential load resistor is symmetrically divided into two 50 Ohm resistors and the common mode voltage is set to 600 mV via a feedback loop. To generate a 500 mV peak to peak swing, 2.5 mA current must flow through the differential load resistor and the 100 Ohm termination resistor as well. Therefore, PMOS transistors must be able to drive high amount of current and possess large device sizes. Following the PMOS drivers and differential load resistors, NMOS transistors are used as switches to prevent or permit the current flow through the legs by turning off and on with respect to input pulse. At the bottom of the circuit, an NMOS transistor functions as a current sink which needs to flow 5 mA of current to ground. Current sink's input voltage is a function of the common-mode node and set by common-mode feedback loop.

9451-95, Session PTue

A study of doping influences on transmission of large-diameter gallium antimonide substrates for long-wave (LWIR) to very long wavelength (VLWIR) infrared applications

Rebecca J. Martinez, IQE IR (United Kingdom); Andrew Mowbray, Brian Smith, Marius Tybjerg, Wafer Technology Ltd. (United Kingdom); Mark J. Furlong, IQE IR (United Kingdom)

Gallium antimonide (GaSb) is an important Group III-V compound semiconductor for infra-red (IR) photodetectors used in sensing and imaging applications. Operating in the mid (3-5 μm) to long wavelength region (8-12 μm) of the IR spectrum, the application of GaSb detectors are extensive, encompassing military, industrial, medical and environmental uses. A significant developing technology for GaSb based detectors are those effective in the very long wavelength (VLWIR) infra-red region (13

μm and beyond) which are advantageous in space and stealth based applications which necessitate high operating temperatures. In this study different doping levels of GaSb are considered and the IR transmission spectra examined by Fourier Transform IR analysis (FTIR). GaSb n- type doped material consistent in delivering long to very long wavelength transmission is demonstrated which is preferable to p-type material which requires backside thinning for IR transmission. The Czochralski (Cz) grown GaSb wafers are assessed for electrical quality and uniformity results on Hall mobility, resistivity and carrier level reported. Results of this work will establish the carrier concentration that ultimately results in high transparency substrates. The doping uniformity in larger diameter substrates (100mm to 150mm) is examined and the material quality and consistency demonstrated post epitaxial growth. In summary enhancements in room temperature IR transmission will be shown to be achieved in GaSb bulk crystals by tellurium (Te) compensation.

9451-96, Session PTue

A 640x480-17μm ROIC for uncooled microbolometer FPAs

Selim Eminoglu, MikroSens Elektronik San ve Tic A S (Turkey)

No Abstract Available

9451-97, Session PTue

SiO2 films mask processed by lift-off techniques for plasma etching of HgCdTe

Yiyu Chen, Univ. of Chinese Academy of Sciences (China); Zhenhua Ye, Shanghai Institute of Technical Physics (China)

High anisotropy etching process with low etch induced damage is necessary for the advanced HgCdTe IRFPAs. Inductive Coupled Plasma (ICP) enhanced Reactive Ion Etching (RIE) technique is adapted to perform these IRFPAs devices. An accurately patterned mask with sharp edges is decisive to accomplish pattern duplication. It has been reported by some researchers that the SiO2 (silicon dioxide) mask functions well in etching HgCdTe with high selectivity. However, the wet process in patterning the SiO2 mask is limited by ambiguous edges and nonuniform patterns. Some other processes are too complicated to be effectively applied on large dimension wafers. Lift-off technique was then carried out to define accurate and uniform silicon dioxide mask. In this report, a 70nm ZnS film was formed to avoid any possible damage in the magnetron sputtering process by thermal evaporation prior to the SiO2 deposition. Then an improved lift-off process was applied. Due to high selectivity between SiO2 and HgCdTe, the etch bias could be greatly suppressed. The well-defined SiO2 pattern and the etched smooth surfaces were investigated with Scanning Electron Microscopy (SEM) and Atomic Force Microscope (AFM). This new developed lift-off process could define the patterns accurately and continuously, which was beneficial for the delineation of decreasing pixels while fabricating large format IRFPAs.

9451-98, Session PTue

Thermal stability of atomic layer deposition Al2O3 film on HgCdTe

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As infrared technology develops, the passivation process on high aspect-ratio HgCdTe mesa arrays produces a new challenge on the traditional thin-film deposition technologies. Atomic Layer Deposition is a unique technology to meet these challenges because of its precise control in the film thickness and compositions, excellent uniformity on high aspect-ratio pattern. Thermal stability of Atomic Layer Deposition Al2O3 film on HgCdTe has been studied by two steps of experiments. The effectiveness of Al2O3 film was evaluated by measuring minority carrier lifetime and dielectric constant. In the first experiment, two devices were fabricated with identical HgCdTe samples and Al2O3 film of one device was annealed at 180? for 180s. This step was mainly used to evaluate the Al2O3 film's compatibility with subsequent processes. Minority carrier lifetime increased by an order of magnitude after Al2O3 deposition and presented a slight decrease after Al2O3 anneal. In the second experiment, the two finished devices were both annealed at 75? for 48h. This step was mainly used to evaluate the passivation reliability of the device, especially the thermal stability. According to the C-V measurements, the calculated dielectric constant was about 7. The device with annealed Al2O3 film presented a decreasing dielectric constant and fixed charge after device anneal. The device with unannealed Al2O3 film presented an increasing dielectric constant and fixed charge after device anneal. The experimental results demonstrated that atomic layer deposition Al2O3 film on high aspect-ratio HgCdTe IRFPAs is feasible and stable.

9451-99, Session PTue

Preliminary validation results of an ASIC for the readout and control of near-infrared large array detectors

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This work describes the preliminary results of the design validation performed on the Near Infrared Readout and Controller ASIC (NIRCA) for large area image sensors. The project aims at future astronomical science and Earth observation missions, where the ASIC will be used with image sensors based on mercury cadmium telluride (HgCdTe, or MCT, currently under development independently at CEA-LETI and SELEX UK). The applications require high spectral sensitivity, very low noise and environmental durability. NIRCA is also interesting for other hybrid image sensors (HAWAII-2RG, and MCT Research at FFI in Norway), which require a readout and controller ASIC. Besides our work, there are other European ongoing developments aiming at similar applications and requirements (independently at CAELESTE and SRON).

The NIRCA can directly connect to the ROIC and to the instrument electronics. It provides to the ROIC regulated power supplies, biases, and fully programmable digital sequences with ADC sample control. Both analog and digital output from the ROIC can be sampled, and the digitized image data is delivered to the instrument. Additionally the NIRCA provides temperature measurement, and monitors several analog and digital signals. The NIRCA is designed to be able to operate from 77 K and to be tolerant against radiation (SEE LET > 60 MeVcm2/mg).

The analogue front-end of the NIRCA provides 4 inputs to preamplifiers with single-ended to differential conversion, 5 different gain setting (1x to 16x), as well as offset cancellation and level shifting, to optimize the dynamic range for the ADC. Each preamplifier connects to a 12-bit ADC designed for a differential input swing of ±2 V and a maximum 3 MSps conversion rate. NIRCA provides programmable regulators from 1.8 V to 3.3 V with a ripple of less than 10 μV and a PSRR of 40 dB. Internally the NIRCA contains a programmable sequencer (32 arbitrary digital waveforms and controls, in addition to sampling triggers, and auxiliary control functions). The NIRCA provides the CIS with reference and bias voltages programmable up to 10 bits with a dynamic range from 0 V to approximately 3 V. NIRCA is controlled through an SPI interface, which allows writing to configuration

registers and memory for the programmable sequencer. Access to a common serial peripheral interface (SPI) is provided for an external system to interface with an SPI to the CIS.

NIRCA is implemented in a mature 0.35 μm CMOS process from a European foundry. Internal registers in the ASIC will have Single Event Upset (SEU) detection and single bit correction. The ASIC is made to tolerate Single Event Latchup (SEL) using design and layout techniques. Test vehicles have been manufactured and validated with respect to both radiation and temperature. Simulations and measurements at low temperatures have been performed to verify the accuracy of the simulation models. The NIRCA ASIC has been manufactured and design validation is being performed. The design validation verifies that the ASIC contains the functionality and the characteristics that it is designed for and aims to confirm the functional, performance, interface and compatibility requirements.

9451-101, Session PS2

Survivability of Corning durable silver-based multispectral mirrors

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Survivability testing results for Corning Durable Silver based multispectral mirrors are presented. These tests were designed to estimate the life of these mirrors when exposed to extreme environments. They were and continue to be used in assisting with the adjustment of designs to enhance mirror longevity. Discussions will include various designs and their survivability in various environments. Spectral performance is monitored along with the optics physical appearance, in order to capture any throughput loss and defect quantification with chemical analysis information. Results from samples exposed to actual flight conditions are discussed and some comparison testing with other vendor silver stack options, such as the known heritage silver coating stack, is presented.

9451-35, Session 10

Infrared SWAP detectors: pushing the limits

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The growing demand for compact and low consumption infrared cooled detectors is driven by different products segments. Hand Held Thermal Imagers, UAV, small gimbals are some of them. End users are requiring devices easy to use with fast cool down time, excellent portability, low acoustic noise with no trade-offs in reliability and performance. These requirements are pushing the technology developments toward constant innovations on detectors, coolers, read out circuits and proximity electronic boards.

In this paper we will discuss the different figures of merit; we will highlight the challenges for the different components. An update on the developments of HOT technology for most advanced pixel pitch will be presented.

The advantages and results of the use of digital outputs for the ROIC will be discussed as it allows significant system performance improvements. Also very compact products are driving the developments for innovative coolers and cryogenic solutions. A low power yet compact architecture is a must for electronic boards to optimize the overall system power consumption. Finally a look to the future requirements for further shrink will be addressed.

9451-36, Session 10

Firefly: A HOT camera core for thermal imagers with enhanced functionality

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Over recent years advances in High Operating Temperature (HOT) MWIR detectors such as those based on mercury cadmium telluride (MCT) grown by Metal Organic Vapour Phase Epitaxy (MOVPE) have reduced the steady state cooling power to a level comparable to the combined power consumption of the digitization and image processing electronics required to operate the detector. At this point one can no longer focus only on reducing cooling power to make further reductions in total system Size Weight and Power (SWAP). By taking a systems engineering approach and considering the infrared detector as one component in a low power imaging system it has been possible to realise a design that reduces the SWAP of the system as a whole.

This paper describes the architecture of the Firefly infrared module, a new generation of infrared camera core developed by Selex ES. Firefly includes a new ROIC designed to reduce the power consumption of digitisation electronics and a multifunction processing core which reduces system complexity by allowing peripheral devices such as laser rangefinders to be controlled directly by the core without additional circuitry. A software based rendering engine enables the flexibility to meet the evolving requirements of modern battlespace systems. Recent advances in silicon technology have allowed the inclusion of such broad functionality without adding significant cost or power consumption overheads. The design trades are examined in detail and the flexibility of the system is illustrated by examining a number of integration scenarios. Empirical data will be presented for electrical power consumption and image processing capacity.

9451-37, Session 10

Fabrication of high-operating temperature (HOT), MWIR transparent photon-trap barrier-based detectors

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We describe our efforts in developing mid-wave (3μm- 5.0 μm) transparent photon-trap InAsSb-based infrared detectors grown on GaAs substrates operating at high operating temperature (150K) with very low dark current. A novel detector design based-on transparent pyramidal photon-trapping structures has been utilized in conjunction with compound barrier-based device architecture. At high operating temperature, diffusion current is a major source of dark current and can be suppressed through absorber volume reduction by using a thin layer (1-2μm) of absorbing InAsSb material opposed to conventional thick (≥ 4-5μm) absorber layer. To enhance optical absorption and quantum efficiency for the thin absorber, the pyramidal photon-trap structures which acting as an anti-reflective coating are fabricated into the non-absorbing InAs layer grown over the thin layer of absorbing bulk InAsSb. The InAs layer will be transparent at the MWIR and there will be no absorption or loss associated with this layer. A thin layer of (1 and 2μm) lattice-mismatched InAsSb with 5.0 μm cutoff at 150K and 5 μm non-absorbing InAs layer was grown by MBE. 320x256/30μm detector arrays that consist of bulk thin absorber as well as transparent photon-trap pyramid structures were fabricated to compare the detector performance. The measured dark current density for the diodes with the transparent pyramidal absorber was 3-5X lower that for the conventional diode with the bulk thick absorber, which is consistent with the volume reduction due to thinner absorber layer. We have achieved median low dark current density of 5.5x10-6 A/cm2 with NEdT of 9mK (f/2-optics) at 150K.

"The views expressed are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government." This is in accordance with DoDI 5230.29, January 8, 2009."

9451-38, Session 10

High-operating temperature MWIR unipolar barrier photodetectors based on strained layer superlattices

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The realization of high operating temperature (HOT) midwave infrared (MWIR) photodetectors would significantly relax the requirements imposed on the cooling system, which would lead to a reduction in the size, weight, and cost of the detection system. One of the most attractive material systems to develop HOT photodetectors is InAs/GaSb Type II Superlattices (T2SLs). This is due the ability of T2SLs materials to engineer the band structure of the device, which can be exploited to make devices with unipolar barriers. It has been shown that the use of unipolar barriers can dramatically reduce the dark current levels of the device, which is essential to realize HOT photodetectors. In this work, we report on the design, growth, and fabrication of MWIR HOT photodetectors based on InAs/GaSb T2SLs. We have designed, grown, and fabricated band-structure engineered MWIR photodetectors based on the pBiBn architecture.

9451-39, Session 10

Effects of AlSb interfaces on InAs/InAsSb type-II infrared superlattice material properties

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Electron and hole barriers and their comprising materials are key design parameters for current type-II superlattice infrared detectors due to their ability to reduce dark current and limit surface recombination. Where the large bandgap barriers interface with smaller bandgap superlattices, band bending is introduced, with the degree of bending depending on the doping levels. This barrier-superlattice interface may also contribute additional carriers to the superlattice due to defect levels at the interface or within the barrier bandgap. The band bending and defect levels can affect the superlattice material characterization results. Barriers have been reported as necessary to reduce surface recombination in order to obtain the minority carrier lifetime in the superlattice using time-resolved photoluminescence for InAs/GaSb superlattices and as unnecessary for InAs/InAsSb superlattices. Here effects of AlSb and GaSb layers at the superlattice-surface and superlattice-buffer interfaces on the electrical and optical properties of an InAs/InAsSb long-wavelength infrared superlattice are examined. Preliminary results show that the low-temperature Hall Effect mobility of the sample with AlSb is five times higher than that of the sample with GaSb and that the low-temperature photoluminescence intensity is higher with AlSb than with GaSb layers. Excitation-dependent photoluminescence results from 12 K to 130 K indicate that the effective Shockley-Read-Hall recombination rate in the superlattice is higher with AlSb than with GaSb layers. Further electrical and optical characterization outcomes and the effects of the barriers on the superlattice material parameters will be discussed.

9451-40, Session 10

Progress on the development of interband cascade photodetectors *(Invited Paper)*

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The InAs/GaSb type-II superlattice (T2-SL) based interband cascade (IC) photodetectors are emerging as a viable candidate for high performance infrared (IR) detectors [1-4], particularly for high operating temperature applications [2-4]. It takes full advantage of the great versatility in energy-band alignment in InAs/GaSb/AlSb material systems with a multiple-stage design [1-3]. In each stage of the IC detector design, the InAs/GaSb T2-SL absorber is sandwiched between electron and hole barriers, which efficiently block the majority carriers without impending the photo-carrier transport. In addition, an ultra-fast carrier relaxation channel is implemented by carefully construct a series of coupled quantum-wells (QWs) adjacent to the absorbers, to facilitate highly efficient photo-carrier extractions in IC detectors [2-3]. These multiple-stages are electrically connected in series, via the type-II broken-gap alignment between InAs and GaSb quantum structures [1-2]. 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. The first IC focal plane array has also been demonstrated and is operational up to 180 K.

In this talk, we will present our latest progress on the development of high performance IC photodetectors in both mid- and longwave-IR. Our results show significant improvement in both the electrical and optical performances for IC detectors. Our mid-IR detectors show zero-bias operation, with external quantum efficiency as high as 11%. The dark current is as low as 1.75 nA/cm2 at 120 K and -10mV, which shows 5 times improvement at lower temperatures. The Johnson-limited D* of the mid-IR detector is around 1.15x1011 Jone at 200 K, showing nearly 10 times improvement compared to the previous results [2,3]. These mid-IR IC detectors have obtained background limited operation up to 210 K. Progress in LWIR IC detectors are also made and will be presented. Furthermore, our very recent progress on the understanding of device physics in quantum-engineered IC detectors, including the dark current mechanisms will also be discussed.

9451-41, Session 10

Numerical analysis of CdS/PbSe room temperature mid-infrared heterojunction photovoltaic detectors

Binbin Weng, Jijun Qiu, Wanyin Ge, Zhisheng Shi, The Univ. of Oklahoma (United States)

Theoretical constrains of a CdS/PbSe room-temperature heterojunction photovoltaic mid-infrared detector are discussed as to provide guidelines for future experimental improvement based on the previous experimental exploration . As reported, the polycrystalline CdS film was prepared on top of the monocrystalline PbSe grown by molecular beam epitaxy method. Various material and device parameters including electron affinity, carrier concentration, interface recombination velocity remain uncertain or ambiguous. However, these parameters could have detrimental effect on the device performance of the CdS/PbSe detector. In this work, therefore, the numerical analysis will be majorly based on these parameters through device modeling and simulation.

9451-42, Session 10

Long-wave infrared HgCdTe unipolar PBνn photodetector

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(China) and National Laboratory for Infrared Physics, Shanghai Institute of Technical Physics, Chinese Academy o (China); Weida Hu, Shanghai Institute of Technical Physics (China); Xiang-Ai Cheng, National Univ. of Defense Technology (China); Tian Jiang, College of Photoelectric Science and Engineering, National University of Defense Technology (China); xiaoshuang Chen, Shanghai Institute of Technical Physics (China)

Unipolar barrier structure has been proven to be an effective method for reducing dark current components in infrared photodetectors. More recently, hot (operate at a high temperature) and dual-band infrared detectors are a hot focus and challenge objective of current research. In this paper, we report on the design and modeling of HgCdTe PBvn photodetectors based on bandgap-engineering, which is used in dual-band devices. Numerical simulation was applied to calculate the current-voltage (I-V) characteristic and R0A values for PBvn unipolar barrier photodiodes and traditional pn junction photodiodes. The results show that the performance of PBvn unipolar barrier device has significantly improved compared with that of conventional pn device. Auger-suppressed is clearly observed when the PBvn device operates at non-equilibrium state at a temperature of 140K, and the responsivity is also improved. Therefore, the PBvn structure may be an ideal choice for fabricating hot double-color devices.

9451-104, Session 10

MOCVD grown HgCdTe p+BnN+ barrier detector for MWIR HOT operation *(Invited Paper)*

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Recently, there has been considerable progress towards the materials development and device design innovations for infrared (IR) photodetectors. One of the leading topics are barrier detectors. Barrier detector in the nBn configuration requires a proper bandgap engineering. The barrier in the conduction band should be high enough to block the electron flow from the cap layer to the absorber, while in the valence band there should be no discontinuity to allow unimpeded transport of photogenerated holes. More generally, zero valence band offset is the key item limiting the performance of nBn detectors [1 5]. In HgCdTe material system, nBn concept cannot be easily realised due to the significant valence band offset, as well as the difficulties posed by heterostructure interface instabilities. In spite of these hurdles, HgCdTe nBn devices operating in mid-wavelength infrared (MWIR) range were presented by Itsuno et al. [6]. The device was grown on a bulk CdZnTe substrate using molecular beam epitaxy (MBE). Uniform n-type doping ensures the absence of depletion in the narrow bandgap layers; however, provide the existence of valence bands offset. First MWIR HgCdTe barrier detectors with a zero valence band offset were presented by Kopytko et al. [7]. The epitaxial structure with a configuration of p+BpnN+ was grown using MOCVD method on GaAs substrate after CdTe buffer layer.

The paper present the electrical and optical properties of MWIR HgCdTe p+BpnN+ barrier photodetectors operating at room temperature. Initial experiments indicate the influence of the barrier on electrical and optical performances of the device. The devices exhibit very low dark current densities in the range of (2÷3)?10–3 A/cm2 at 300 K. The estimated thermal activation energy of about 0.33 eV is close to the full Hg0.64Cd0.36Te bandgap (Fig. 1), which in zero temperature equals to 0.327 eV [8]. This indicate diffusion limited dark currents.

The structures with a round mesa geometry were defined by a standard optical photolithography and fabricated by wet chemical etching with Br:HBr (1:100) solution. Since the deep etching reveals side walls around the absorber layer and the mesa's slopes have not been passivated, the surface leakage current was not negligible for small devices. The dark current decreased with an increase in junction area and is the same for devices with 400 and 500 μm diameters (Fig. 2). The estimated surface leakage current of the detector equals to 0.155 mA/cm at -0.2 V and 300 K.

Due to the large photoresponse of about 2 A/W at zero bias and in a wide range of reverse bias voltages (Fig. 3), those devices have a zero valence band offset and are able to operate at near zero-bias voltage.

9451-43, Session 11

Uncooled infrared focal plane array imaging in China *(Invited Paper)*

Shuyu Lei, North GuangWei Technology Inc. (China)

This article reviews the development of uncooloed infrared focal plane array imaging in China in the past decade. Sensors based on optical or electrical read-out mechanism were developed but the latter dominates the market. In resistive bolometers, VOx and amorphous silicon are still the two major thermal-sensing material. The specifications of the IRFPA made by different manufactures were collected and compared. Currently more than five Chinese companies and institutions design and fabricate uncooleded infrared focal plane array. Some devices have sensitivity as high as 30 mK; the largest array for commercial products is 640*512 and the smallest pixel size is 17 um. Emphasis is given on the MEMS design, ROIC design, fabrication, and packaging of the IRFPA manufactured by GWIC, especailly on design for high sensitivities, low noise, better uniformity and linearity, better stabilization for whole working temperature range, full-digital design, low cost and high high performance WLP, etc.

9451-44, Session 11

Uncooled infrared detector and imager development at DALI technology

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Zhejiang Dali Technology Co Ltd is one of the major players in China Infrared industry. The company has been working on infrared imagers using uncooled FPAs for more than 15 years. It started the research and development of uncooled microbolometer detectors since 2006, and has mass producted several different format detectors, including 35um 384x288, 25um 160x120, 384x288, 640x480, 17um 384x288, 640x480. The developed detectors have been used in imagers such as thermography cameras and automotive night vision imagers. In this presentation, we will describe the development and status of uncooled detectors and imagers at DALI Technology.

9451-45, Session 11

BAE Systems' SMART Chip Camera FPA development *(Invited Paper)*

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BAE Systems' SMART Chip camera combines 12 μm wafer level packaged FPA with multichip stack ASIC and wafer level optics to provide very compact LWIR solutions. The key innovations include single-layer 12 μm pixel bolometer design and robust fabrication process, as well as wafer-level lid packaging. We have used advanced packaging techniques to achieve an extremely small form-factor camera presenting a complete camera volume of 2.9 cm3 and a thermal core weight of 5.1g. The SMART Chip camera supports up to 60 Hz frame rates and requires less than 500 mW of power.

9451-46, Session 11

Advanced uncooled sensor product development *(Invited Paper)*

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Raytheon and its partners, SEEK Thermal and Freescale continue on the path to bring the latest technology and innovation to both the military and commercial customers. Raytheon with its partners have matured the 17 um pixel for volume production on the TWS (Thermal Weapon Sight) program in efforts to bring advanced production capability to produce a low cost, high performance product. Raytheon has developed the 12 micron pixel and has demonstrated performance across a family of detector sizes ranging from formats as small as 206 x 157 to full High Definition formats. Detector pixel sensitivities have been achieved using the Raytheon double level advanced pixel structure. Transition of the packaging of microbolometers from a traditional die level package to a Wafer Level Package (WLP) in a high volume commercial environment is complete. Innovations in wafer fabrication techniques have been incorporated into this product line to assist in the high yield required for volume production. The WLP seal yield is currently > 95%. Simulated package vacuum lives >> 20 years have been demonstrated through accelerated life testing where the package has been shown to have no degradation after 2,500 hours at 150C. Additionally the rugged assembly has shown no degradation after thermal shock and weapons fire testing. The transition to production effort was successfully completed in 2014 and the WLP design has been integrated into multiple new production products including the TWS and the innovative SEEK Thermal commercial product that interfaces directly to an iPhone or android device.

9451-47, Session 11

On-orbit performance of the compact infrared camera (CIRC) with uncooled infrared detector

Haruyoshi Katayama, Michito Sakai, Eri Kato, Yasuhiro Nakajima, Toshiyoshi Kimura, Japan Aerospace Exploration Agency (Japan); Koji Nakau, Hokkaido Univ. (Japan)

We have developed the Compact Infrared Camera (CIRC) with an uncooled infrared array detector (microbolometer) for space application. The CIRC is an infrared sensor intended for observing wildfires, volcanoes, and heat island phenomena. Microbolometers have an advantage of not requiring cooling system such as a mechanical cooler, and is suitable for resource-limited sensor system. Another characteristic of the CIRC is its use of athermal optics. The athermal optics system compensates for defocus owing to temperature changes by utilizing a combination of different lens materials and diffractive lenses.. The CIRC can keep the optical performance at ambient temperature ranging from ?15 to 50 °C. We also employ a shutterless system which is a method to correct non-uniformity of the detector without a mechanical shutter. The CIRC achieves a small size (approximately 200 mm), light mass (approximately 3 kg), and low electrical power consumption (<20 W) by employing athermal optics and a shutterless system.

The CIRC was launched in May 2014 as a technology-demonstration payload of Advanced Land Observation Satellite-2 (ALOS-2). In the initial functional verification phase (July 4-14, 2014), the athermal optics and the shutterless system showed a good performance according to its intended design. We also confirmed the temperature accuracy of the CIRC observation data is within 4K without a calibration function. The CIRC also detected more than 900 wildfires and observed the volcano activities in various areas.

In this paper, we present the on-orbit performance of the CIRC onboard ALOS-2.

9451-48, Session 11

Low-SWaP shutterless uncooled video core by SCD

Udi Mizrahi, Yair Lury, Yaakov Gridish, Shahar Yuval, Nickolay Syrel, Yaron Shamay, Roman Meshorer, Roman Iosevich, Shibolet L. Horesh, SCD SemiConductor Devices (Israel)

Over the last decade SCD has established a state of the art VOx μ-Bolometer product line. The markets demand for low SWaP (Size, Weight and Power) uncooled engines is growing, where low SWaP is especially critical in battery-operated applications such as goggles and Thermal Weapon Sights.

In this approach, SCD have developed a low-SWaP, shutter-less uncooled video core, with a foot-print of 30x30mm and power consumption less than 1W. The video core contain a temperature calibrated, HS (high-sensitive) 640x480 17μm pitch detector (NETD ≤ 32mK), packed (without TEC) in a new ceramic package (26x23mm).

The video core has excellent image processing algorithms, like local and global DRC (Dynamic Range Compression), and de-noising algorithms (spatial and temporal), which gives low NETD (Noise Equivalent Temperature Different) and stable and low RNU (Residual Non Uniformity) video.

9451-49, Session 12

Improving the shutter-less compensation method for TEC-less microbolometer-based infrared cameras

Alexander Tempelhahn, Helmut Budzier, Volker Krause, Gerald Gerlach, Technische Univ. Dresden (Germany)

The present trend of miniaturizing microbolometer focal plane arrays (FPAs) enables infrared thermography to discover new fields of application, e.g. smart phone devices or sensors for smart building control systems. These applications require compact, robust and simple-constructed infrared cameras with low power consumption. For that reason, infrared cameras should consist only of the sensor array, the infrared lens system and the digital signal processing unit (DSP).

The influences of changing ambient conditions, especially of the ambient temperature, are the main sources of measurement uncertainty and need to be addressed. In [1] we have shown that it is possible to compensate changes in the disturbing radiation derived from the interior of the camera housing for infrared cameras with temperature-stabilized sensor arrays using several additional thermometers placed inside the camera housing. In this paper we improve this approach for infrared cameras without temperature stabilization (TEC-less). Here changes of the ambient temperature affect the sensor temperature due to heat conduction; and the two main sensor parameters, pixel responsivity and pixel offset, follow this sensor temperature change. In order to compensate that we adapt the approach mentioned in [2] for shutter-less infrared cameras. The changes of the pixel responsivity due to the changing sensor temperature are estimated within an additional calibration step. The estimation of the changing pixel offset is combined with the estimation of the disturbing inside-camera radiation mentioned in [1]. The results of this compensation approach are compared to the known shutter-based method.

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9451-50, Session 12

Implementation and performance of shutterless uncooled micro-bolometer cameras

Jo Das, Danny De Gaspari, Philippe Cornet, Pieter D. Deroo, Jan P. Vermeiren, Xenics NV (Belgium); Patrick J. Merken, Xenics NV (Belgium) and Royal Military Academy (Belgium)

Nowadays micro-bolometer cameras are equipped with a mechanical shutter to compensate for pixel offset due to temperature effects. An undesired consequence of the shutter operation is that the camera is blinded during the re-calibration period, which is not acceptable in safety critical applications related to security or critical observation and to monitoring for machine-vision.

For these applications a shutterless approach is proposed, that is implemented into the Xenics LWIR thermal cameras and cores. The shutterless camera can have either a cameralink or analog output interface, and has a power consumption of less than 2W.

Based on a set of calibration images the optimal non-uniformity correction is calculated onboard of the camera. The calibration data is taken for different integration times of the bolometer, and also a temperature coefficient is included into the model. Due to the limited resources in the camera the compactness of the algorithm and the efficiency of the coding is very important.

We will present in this paper the performance of the shutterless algorithm. The residual FPN is analyzed at different integration times, black body (0-120°C) and ambient (up to 60°C) temperatures, and compared to a traditional shutter-based offset correction. Also the long term stability of the algorithm is investigated.

9451-51, Session 12

Shutters with embedded processors

Stanley W. Stephenson, Melles Griot (United States)

Shutters are used to periodically provide a non-uniformity correction (NUC) calibration surface to micro-bolometers. Many micro-bolometer applications, such as TWS and DVE, require compact, power efficient actuators. Actuators in these applications, such as bistable solenoids and stepper motors, benefit from complex drive schemes. Consumer electronics products have generated compact, low-cost drive components that can be used to embed complex drives into these shutters. Shutter drives using these components maintain compactness and power efficiency while simplifying interfaces at minimal cost. Recently, several commercially available shutter systems have been created that incorporate embedded microprocessors into shutters usable for NUC correction of micro-bolometers.

9451-52, Session 12

Enhanced performance of VOx-based bolometer using patterned gold black absorber

Evan M. Smith, Univ. of Central Florida (United States) and Plasmonics, Inc. (United States); Deep Panjwani, Univ. of Central Florida (United States); James C. Ginn III, Andrew Warren, Christopher J. Long, Plasmonics, Inc. (United States); Pedro Figuieredo, Plasmonics, Inc. (United States) and Univ of Central Florida (United States); Christian W. Smith, Univ. of Central Florida (United States); Joshua D. Perlstein, Plasmonics, Inc. (United States); Nick Walter, Carol Hirschmugl, Department of Physics, University of Wisconsin-Milwaukee (United States); Robert E. Peale, Univ. of Central Florida (United States); David J. Shelton, Plasmonics, Inc. (United States)

We have patterned a highly absorbing gold-black film onto the top surface of a vanadium oxide based infrared bolometer. Gold black is a porous, nano-crystalline film, achieved by evaporating gold in a ~1 torr inert atmosphere. While the film is very highly absorbing, it is also extremely fragile. Our method of infusing the gold black layer with evaporated oxide makes the film robust while preserving its near unity absorption. This allows gold-black to be patterned using standard lift-off techniques and even to survive dry-etch removal of sacrificial polyimide used to facilitate air-bridge bolometers. Gold-black coated VOx-based air-bridge bolometers show a clear improvement in infrared responsivity over uncoated devices.

9451-53, Session 12

Three-dimensional plasmonic metamaterial absorbers based on all-metal structures

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

Information such as the shape, position and average radiant intensity of objects can be observed through a typical uncooled infrared (IR) sensor; however, color (wavelength) information cannot be obtained. If an uncooled IR sensor with a wavelength selective function could be realized, then advanced uncooled IR sensors with color information and multicolor imaging could be developed, which would be advantageous for fire detection, gas analysis and analytical applications. Small pixel structures maintaining high absorption are strongly required in order to realize high-performance uncooled infrared sensors for multi-color imaging. Three-dimensional plasmonic metamaterial absorbers (3D-PMAs) based on full-metal structures were fabricated. 3D-PMAs consist of the two-dimensional periodic micropatches and the bottom plate which are connected through the finite posts. All components of the 3D-PMA are based on plasmonic metals such as Au. 3D-PMAs were constructed by the two-step lift-off procedure with a carbon sacrifice layer. The 200 nm gap was achieved with the finite post. Measurement of the reflection demonstrates that the wavelength-selective absorption is realized and the absorption wavelength is defined by the micropatch size, regardless of the micropatch array period and is longer than the micropatch array period. A strong wavelength selective absorption is realized by the plasmonic resonant mode localized at the edge of the micropatch and the narrow-gap resonant mode between the micropatch and the plate. The disturbance of the metal post for both resonance modes is negligible. Full metal structures have no additional mode comparing to typical metal-insulator-metal absorbers. 3D-PMAs have the small volume and the absorption wavelength beyond the period, which result in the fast response and the small pixel size. The results obtained here will contribute to the development of high-performance uncooled IR sensors for multicolor imaging.

9451-54, Session 13

Design and high-volume manufacture of low-cost molded IR aspheres for personal thermal imaging devices

Amy L. Zelazny, Kenneth F. Walsh, John P. Deegan, Brian Bundschuh, Edward K. Patton, Rochester Precision Optics, LLC (United States)

The demand for infrared optical elements, particularly those made of chalcogenide materials, is rapidly increasing as thermal imaging becomes affordable to the consumer. The use of these materials in conjunction with established lens manufacturing techniques presents unique challenges relative to the cost sensitive nature of this new market. We explore the

process from design to manufacture, and discuss the technical challenges involved. Additionally, facets of the development process including manufacturing logistics, packaging, supply chain management, and qualification are discussed.

9451-55, Session 13

Design and fabrication of multispectral optics using expanded glass map

Shyam S. Bayya, Daniel J. Gibson, Vinh Q. Nguyen, Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States); Mikhail Kotov, Sotera Defense Solutions, Inc. (United States); Gryphon Drake, Univ. Research Foundation (United States); John P. Deegan, George P. Lindberg, Rochester Precision Optics, LLC (United States)

There is a strong desire to reduce size and weight of single and multiband IR imaging systems in ISR operations on hand-held, helmet mounted or airborne platforms. Current systems are limited by bulky optics. We have recently developed a large number of new optical materials based on chalcogenide glasses which transmit in SWIR to LWIR wavelength region that 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. These glasses were specifically designed to have comparable glass molding temperatures and thermal properties to be able to laminate and co-mold the optics and reduce the number of air-glass interfaces (lower Fresnel reflection losses). These new NRL glasses also have negative or very low positive dn/dT making it easier to athermalize the optical system. Our multispectral optics designs using these new materials demonstrate reduced size, complexity and improved performance. This presentation will cover discussions on the new optical materials, multispectral designs, fabrication and characterization of new optics.

9451-56, Session 13

Investigation of As40Se60 chalcogenide glass in precision glass molding for high-volume thermal imaging lenses

Alan Symmons, William V. Moreshead, Jacklyn Novak, Jeremy Huddleston, Edward Foote, LightPath Technologies, Inc. (United States)

The growing demand for thermal imaging sensors and cameras has focused attention on the need for larger volumes of lower cost optics in this infrared region. A major component of the cost of thermal imaging lenses is the Germanium content. As40Se60 was developed as a moldable, germanium-free chalcogenide glass that can serve as a low cost alternative to germanium and other infrared materials. As40Se60 has found acceptance as a material to be diamond turned or polished, but has not been widely used for molding as originally anticipated. This paper will review the challenges of chalcogenide molding and characterize As40Se60 for widespread use in high volume molded thermal imaging optics. The relative advantages and disadvantages of As40Se60 as compared to other chalcogenide glasses and other traditional infrared materials will also be discussed.

9451-57, Session 13

GRIN optics for multispectral infrared imaging *(Invited Paper)*

Daniel J. Gibson, Shyam S. Bayya, Jasbinder S. Sanghera, Vinh Q. Nguyen, U.S. Naval Research Lab. (United States); Mikhail Kotov, Sotera Defense Solutions, Inc. (United States); Gryphon Drake, Univ. Research Foundation (United States)

Graded index (GRIN) optics offer potential for both weight savings and increased performance but have so far been limited to visible and NIR bands (wavelengths shorter than about 0.9 μm). NRL is developing a capability to extend GRIN optics to longer wavelengths in the infrared by exploiting diffused IR transmitting chalcogenide glasses. These IR-GRIN lenses are compatible with all IR wavebands (SWIR, MWIR and LWIR) and can be used alongside conventional wideband materials. Traditional multiband IR imagers require many elements for correction of chromatic aberrations, making them large and heavy and not well-suited for weight sensitive platforms. IR-GRIN optical elements designed with simultaneous optical power and chromatic correction can reduce the number of elements in wideband systems, making multi-band IR imaging practical for platforms including small UAVs and soldier handheld, helmet or weapon mounted cameras. The IR-GRIN lens technology, design space and anti-reflection considerations will be presented in this paper.

9451-58, Session 13

Index change of chalcogenide materials from precision glass molding processes

John P. Deegan, George P. Lindberg, Robert Benson, Rochester Precision Optics, LLC (United States); Daniel J. Gibson, Shyam S. Bayya, Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States)

With the increase in demand of infrared optics for thermal applications and the use of glass molding of chalcogenide materials to support these higher volume optical designs, an investigation of changes to the optical properties of these materials is required. Typical precision glass molding requires specific thermal conditions for proper lens molding of any type of optical glass. With these conditions a change (reduction) of optical index occurs after molding of all oxide glass types and it is presumed that a similar behavior will happen with chalcogenide based materials. We will discuss the effects of a typical molding thermal cycle for use with commercially and newly developed chalcogenide materials and show results of index variation from nominally established material data.

9451-59, Session 13

Methods of both destructive and non-destructive metrology of GRIN optical elements

George P. Lindberg, John P. Deegan, Robert Benson, Rochester Precision Optics, LLC (United States); Andrew J. Berger, Joseph J. Linden, Univ. of Rochester (United States); Daniel J. Gibson, Shyam S. Bayya, Jasbinder S. Sanghera, Vinh Q. Nguyen, U.S. Naval Research Lab. (United States); Mikhail Kotov, Sotera Defense Solutions, Inc. (United States)

Gradient index (GRIN) optics have been an up-and-coming tool in the world of optics. They have been used primarily in the fiber optic coupling industry. However, by combining an index gradient with a surface curvature the number of optical components for a lens system can be greatly reduced. Current methods of producing GRIN lenses make larger optics prohibitive. Their use in the realm of infra-red is only becoming realized as new efforts are being developed to create materials suitable and intercompatible for these optical components. The materials being pursued are chalcogenide based glasses. Small changes in elemental concentrations in these glasses can have dramatic effects on physical and optical properties. The commonality between these glasses and their widely different optical

properties make them prime candidates for GRIN applications. The difficulty comes in with the metrology of a GRIN optic. Traditional methods of measure are complicated by the combination of the GRIN and the curvature of the element. We will present preliminary data on both destructive and non-destructive means of measuring the gradient index. The most promising destructive methods being sought is interferometry of thinned slices of lenses. Non-destructive methods may require inference of index through material properties, by careful measurement of the individual materials going into the GRIN optic, followed by mapping measurements of the GRIN surface. Methods to be pursued are micro Raman mapping and CT scanning. By knowing the properties of the layers and accurately mapping the interfaces between the layers we should be able to back out the index profile of the GRIN optic and then confirm the profile by destructive means.

9451-65, Session 13

Reducing narcissus with a GRIN *(Invited Paper)*

Jay N. Vizgaitis, Arthur R. Hastings Jr., optX imaging systems (United States)

Narcissus is a habitual problem in infrared systems that often takes a seemingly wonderful design and makes it relatively unusable. It forces further optimization of the surfaces, addition of more lenses, or the reduction in performance to make it go away. If not eliminated, the narcissus reduces dynamic range, reduces contrast, and complicates the overall system by forcing a non-uniformity correction scheme that includes all of the culprit lenses. Adding GRIN lenses to a system adds additional degrees of freedom in the design. Enabled by these degrees of freedom is the manipulation of the curvatures of the lenses of a system to minimize the narcissus impact without the traditional degradation in performance or increase in lens count. This paper explores the design space of including GRIN lenses to improve narcissus in infrared systems.

9451-60, Session 14

Diffractive optics technologies in infrared systems *(Invited Paper)*

Yakov G. Soskind, DHPC Technologies (United States)

The proliferation of diffractive optics technologies into military and consumer markets has been driven by the advancements in modeling, fabrication, and performance characterization of diffractive components.

Diffractive optics offers additional degrees of freedom for controlling the propagation, dispersion, and polarization of light in photonic instruments.

It provides optical developers and designers with additional flexibility in systems' design, resulting in solutions with reduced overall size and weight, as well as enhanced performance.

Diffractive optics is playing an increasingly important role in spectral regions where optical quality vitreous materials are sparse or not available. That applies especially to long-wave infrared and THz spectral regions, where diffractive optics performs exceptionally well.

In this paper I will compare unique benefits offered by using diffractive optical components in modern photonic instruments, emphasizing successful examples of optical systems and photonic devices enabled by the use of diffractive optics. In addition, I will show that further development of diffractive optics for applications in the IR and THz regions can provide significant system-level performance benefits.

9451-61, Session 14

Varo-Achro-Phobia: the fear of broad spectrum zoom optics

Christopher C. Alexay, Troy A. Palmer, StingRay Optics, LLC (United States)

Today's battlefield is evolving at lightning speed. Our warfighters are being tasked with highly complex missions requiring the very best technology that our industry can offer. The demand for these advanced ISR platforms is challenging designers and engineers in the optics industry to push the envelope and develop wider band solutions to support all multiple and broadband sensor platforms. Recently, significant attention has been directed towards the development of optical systems that enable simultaneous operation in the visible and shortwave infrared spectral wavebands.

This paper will present a review of the evolution of StingRay Optics' GhostSight™ zoom optics that offer broad chromatic imaging capabilities from the visible through the shortwave infrared spectrum.

9451-62, Session 15

Improved optical-to-mechanical software export process for precision systems

Ian B. Murray, Jerry Ma, BAE Systems (United States)

BAE Systems has developed an improved tool for exporting optical design coordinates to Computer-Aided Drafting (CAD) software. Existing scripts within common lens design packages export element shapes and rays which is enough for standard systems, but complex system design requires knowledge of surface vertices and coordinates for each component. Fixed coordinates for each element allows the mechanical engineer to place parts more accurately than allowed by the standard surface export algorithms, as well as locking optical elements in space so that mating surfaces do not inadvertently move optical elements during mechanical optimization. Including optical element vertex coordinates is useful for rotationally-symmetric systems, especially after multiple design iterations, and is essential for multi-channel, off-axis systems where apertures are not centered on surface vertices.

9451-63, Session 15

Cost-effective lightweight mirrors for aerospace and defense

Kenneth S. Woodard, Lovell E. Comstock, Leonard G. Wamboldt, Brian P. Roy, Corning Incorporated (United States)

The demand for high performance, lightweight mirrors was historically driven by aerospace and defense but now we are also seeing similar requirements for commercial applications. These applications range from aerospace-like platforms such as small unmanned aircraft for agricultural, mineral and pollutant aerial mapping to an eye tracking gimbaled mirror for optometry offices. While aerospace and defense businesses can often justify the high cost of exotic low density materials, commercial businesses rarely can. Also, to obtain high performance with low overall optical system weight, aspheric surfaces are often prescribed. This may drive the manufacturing process to diamond machining thus requiring the reflective side of the mirror to be a diamond machinable material.

This paper summarizes the diamond machined finishing and coating of some high performance, lightweight designs using non-exotic substrates to achieve cost effective mirrors. The results indicate that these processes can meet typical aerospace and defense requirements but may also be competitive in some commercial applications.

9451-64, Session 15

An ultra-low surface finish process for 6061-Al mirrors

Leonard G. Wamboldt, Corning Incorporated (United States)

An ultra-low surface finishing process for 6061 type aluminum has been developed by Corning Incorporated, Specialty Materials Division, and has been successfully applied to mirrors up to 12 inches in diameter. This paper presents finish and figure data achieved from this process. Mirror stability is demonstrated through distortion versus delta temperature measurements, over the ambient to cryogenic temperature range. As an added benefit, the process enables the use of deterministic polishing and enhances the reflective optics resistance to corrosion. Survivability of the reflective optic is evaluated through extended extreme temperature cycling and other environment testing. The paper will discuss successful uses of processed optical components on various installed systems.

9451-66, Session 16

Miniature cryocooler developments for high-operating temperatures at Thales Cryogenics

Roel Arts, Thales Cryogenics B.V. (Netherlands); Jean-Yves Martin, Sebastien Van Acker, Thales Cryogénie S.A. (France); Daniel Willems, Jeroen C. Mullié, Thales Cryogenics B.V. (Netherlands); Alexander Göbel, Thales Cryogenics BV (Netherlands); Mark Tops, Thales Cryogenics B.V. (Netherlands); Julien Le Bordays, Thierry Etchanchu, Thales Cryogénie S.A. (France); Tonny Benschop, Thales Cryogenics B.V. (Netherlands)

In recent years there has been a drive towards miniaturized cooled IDCA solutions for low-power, low-mass, low-size products (SWAP). To support this drive, coolers are developed optimized for high-temperature, low heat load dewar-detector assemblies.

In this paper, Thales Cryogenics development activities supporting SWAP are presented. Design choices are discussed and compared to various key requirements, such as high efficiency, short cooldown times, low acoustic noise & vibrations, and small size & mass.

Trade-off analysis results are presented on drive voltage, cold finger definition (length, material, diameter and sealing concept), and other interface considerations. As optimization at cooler level is not always the optimal choice at IDCA or camera level, a link to camera-level considerations such as overall IDCA length and power budgets are discussed. As these system-level considerations affect the cold finger interface definition, this subject is touched upon as well.

In parallel with linear and rotary cooler options, designs for small-size high-efficiency drive electronics based on state-of-the-art architectures are presented, together with a discussion on camera-level electronic architecture choices, such as voltage regulation, digital I/O, and filtering.

9451-67, Session 16

Development and optimization progress with Ricor's cryocoolers for HOT IR detectors

Amiram Katz, Ilan Nachman, Sergey V Riabzev, Dan Gover, Victor Segal, Avishai Filis, 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 the progress made with optimization performed on "HOT" prototypes and engineering pre-production series cryocoolers at the FPA temperature range of 130 - 200K for three different cryocooler models based on rotary & linear design concepts.

The paper will also review the progress with development activities that were implemented in the cryocoolers and the electronic control modules 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 progress in cryocoolers reliability will also be reported in the paper.

9451-68, Session 16

Miniature linear cryocoolers for HOT applications

Ingo N. Ruehlich, Markus Mai, Carsten Rosenhagen, Andreas Withopf, Sebastian Zehner, AIM INFRAROT-MODULE GmbH (Germany)

Mid Wave IR HOT detectors today allow operating temperatures as high as 130K - 150K and current developments predict even higher temperatures for the near future. To achieve improvements in size, weight, power and cost (SWaP,C) improved miniature, long life cryocoolers are demanded.

Since many years developments at AIM are focused to compact, lightweight linear cryocoolers to also achieve highest MTTF targets. The most compact linear compressors are featuring single piston moving magnet driving mechanisms and passive balancer technology.

Linear coolers provide key advantages vs. rotary cooler technology like low audible noise and vibration, high flexibility in IDCA concepts due to split design and finally outstanding MTTF life. The high MTTF significantly reduces total cost of ownership as cooler replacements due to wear-out are completely eliminated for most applications.

In 2014 AIM presented SX020 model which is lightweight (<200g) and compact (< 60mm compressor length) and high efficient (~2W typical power consumption).

In this paper AIM will give an update on qualification and production status for SX020. Status of development of the next smaller cooler SX010 and of a miniature coldfinger (<40mm overall length) including predicted performance data will be presented.

9451-69, Session 16

Multi-slope warm-up calorimetry of Integrated Dewar-Detector Assemblies

Alexander Veprik, Baruch Shlomovich, SCD SemiConductor Devices (Israel); Avi Tuito, Israel Ministry of Defense (Israel)

Characterization of the Integrated Dewar-Detector Assemblies (IDDA) usually relies on the traditional boil-off calorimetry. The parasitic heat load is normally evaluated as the product of the latent heat of vaporization and the "last drop" boil-off rate of the cryogenic coolant (LN2, typically), which is let to isothermally boil off from the IDDA cold well to the atmosphere through the dedicated flow meter.

This approach, producing satisfactory results for the regular 77K IDDA featuring long cold fingers, however, appears to be impractical for the High Operational Temperature (HOT) applications. Beyond the need in using exotic cryogenic coolants boiling at higher than LN2 temperatures, the "last drop" boil-off rate measurement is usually inaccurate and not repeatable for such Dewars usually featuring short cold fingers.

The authors disclose modification and adaptation of the well-known dual-slope calorimetry. The novel technique relies on comparing slopes of the thermal transient processes during the warm-up of the initially precooled IDDA at different amounts of added (trial) heat load.

Theoretical findings are supported by the outcomes of full-scale experimentation. Because of the simplicity, accuracy and ability to perform calorimetry at any temperature of interest, this approach seems to be ideally suited for the HOT IDDAs and shows good potential of entirely replacing the traditional boil-off calorimetry.

9451-70, Session 16

Microsat cryocooler system

Carl S. Kirkconnell, Lauren S. Shaw, Jacinto Dominguez, Michael J. Ellis, Andy Buric, Mitul H. Jambusaria, Iris Technology Corp. (United States)

As the scientific requirements of microsatellites migrate closer to those of larger more-expensive traditional satellites, the technical requirements on the key enabling components and subsystems are becoming more demanding. If the utility of microsatellites is ever to expand to include high performance mid-wave infrared (MWIR) and short-wave infrared (SWIR) sensors, significant advancement in the state of art of small cryocooler systems is required. The Microsat Cryocooler System (MCS) is a radiation hard, space-qualified integrated cryocooler assembly (ICA) for cubesat and microsat applications. The ICA includes a high reliability tactical cryocooler, a miniature set of Low Cost Cryocooler Electronics (mLCCE), the thermal management components, and the isolation structure. As is the case with the larger LCCE from which it was derived, the mLCCE supports any of a wide range of linear cryocoolers in its design output power range (nominally 25W). With minor adaptation, rotary coolers are also supported.

This paper presents the initial results from the brassboard phase of the MCS Program. A high fidelity set of cryocooler electronics with a well-defined upgrade path to a space-compatible design has been built and tested with several cryocoolers. Those data are presented. In addition to reducing risk for the spaceflight design to follow, these electronics are being released as an intermediate product for high-end tactical applications where the plug-and-play operability among different coolers and the enhanced level of control and programmability (relative to typical tactical cooler electronics) are desired.

The overall cubesat-compatible mechanical subsystem design is also presented, including descriptions of the thermal management and vibration isolation approaches.

9451-71, Session 16

Advanced Ricor's cryocoolers for high-end IR missile warning systems and ruggedized platforms

Ilan Nachman, Sergey V Riabzev, Dan Gover, Victor Segal, Avishai Filis, 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 systems, 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 a cryocooler rigid structures approach and cold finger optimization in order to achieve high cooling capacity at high ambient, withstand the high level of vibrations, keep the challenged demand of detector Line of Sight and meet the reliability requirements of the system.

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 extreme temperatures.

As a final stage of development, such cryocoolers were successfully qualified by RICOR in harsh environmental conditions and an accelerated life demonstration test was performed at IDDCA level.

9451-72, Session 17

RMS noise modeling and detection for high-reliability HgCdTe infrared focal plane arrays development

Augustin Cathignol, Guillaume Vauquelin, Alexandre Brunner, Vincent Destefanis, Magalie Maillard, Laurent Rubaldo, SOFRADIR (France)

Sofradir is the world's leader in the development and manufacture of high-tech infrared (IR) detectors for military, space-based and industrial applications. Its vast range of IR products covers the entire spectrum from visible and short-wave infrared to very long-wave infrared. Sofradir keeps innovating in the development of cooled IR detectors using high-performance technologies based on mercury cadmium telluride (MCT) as well as other technologies such as indium antimonide (InSb), indium gallium arsenide (InGaAs) and the quantum-well infrared photo detector (QWIP).

This paper presents recent improvements introduced in production lines of MWIR and LWIR HgCdTe detectors that increase performances, image quality, and reliability. This was achieved thanks to the proper characterization of RMS noise distributions. Based on many MWIR and LWIR devices RMS distributions, a RMS noise distribution model that accounts for both Background Limited diodes and 1/f noise affected diodes is first proposed. Then, a criterion for quantifying the defective pixels that meets the properties detailed above is introduced. This criterion is shown to be easy to use and robust to statistical variability. Moreover, this criterion is also "physical", in the way that the number of defects that are calculated thanks to this criterion do well correlate with other figure of

merit that gauge the material quality or the low frequency noise. The ability to accurately and efficiently quantify RMS noise benefits to Sofradir in its development of highly reliable technologies. Such benefits are illustrated on the latest MWIR and LWIR technologies developed by Sofradir that are demonstrated to be very robust regarding thermal stress and thermal cycling, which directly translates into image quality stability through whole product lifetime.

9451-73, Session 17

MCT by MBE on GaAs at AIM: state of the art and roadmap

Heinrich Figgemeier, Jan Wenisch, Detlef Eich, Stefan Hanna, Wilhelm Schirmacher, Holger Lutz, Timo Schallenberg, Rainer Breiter, AIM INFRAROT-MODULE GmbH (Germany)

For many IR companies, the development of molecular beam epitaxy (MBE) technology as a fabrication process for HgCdTe (MCT) material has been a prime focus to benefit from its considerable cost reduction potential and the capability to produce 3rd generation IR devices. At AIM, the MBE process on the alternative substrate GaAs is making rapid progress since 2009.

In multiple publications over the last years, MCT MBE on GaAs has been shown to be a very versatile and promising material system and indeed may be the prime candidate among the alternative substrates for the fabrication of high-performance detectors across the whole IR composition range. High quality growth will be demonstrated in the Cadmium fraction range 0.2 < x(Cd) < 0.8. The main focus of development at AIM has been the MWIR segment with detector formats of 640 x 512 and 1280 x 1024 pixel with 15 µm pitch. For the former, a pixel operability of 99.5% at an operating temperature of 120 K with low dark current has been reported. In addition to the MWIR band, the performance of MBE grown MCT on GaAs is being evaluated for the LWIR and SWIR regions, both of which are key elements of advanced 3rd generation IR multi-spectral detectors.

This contribution will provide an up to date overview as well as selected highlights of AIM´s MBE technology development across the whole MCT composition range.

9451-75, Session 17

Improved MCT LWIR modules for demanding imaging applications

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

Thermal imagers based on cooled LWIR Modules are the choice for many Army applications in battlefield conditions like e.g. Gunner and Commander Sights in armored vehicles or Pilotage and Targeting Sights for helicopters.

AIM has developed and produces LWIR FPAs based on liquid phase epitaxy (LPE) grown MCT on CZT substrates with different formats up to detector arrays with 1280x1024 elements in a 15µm pitch. LWIR detector arrays with different spectral cut-off wavelengths in the range of 9µm up to >12µm have been produced and characterized.

For cost reduction a fabrication of molecular beam epitaxy (MBE) grown MCT on GaAs substrates is developed.

Critical performance parameters of the detector arrays are temporal noise at low frequencies and the residual fixed pattern noise after non-uniformity correction. A performance limiting factor of a LWIR FPA is also the available full well capacity (FWC) of the readout integrated circuit (ROIC) for signal integration. AIM has done a redesign of the standard 640x512, 15µm pitch ROIC using now 0.18µm Si-CMOS technology. The available FWC for signal integration could be significantly increased resulting in better NETD performance.

Further developments are done for pitch reduction to realize LWIR modules also with 12µm and 10µm pixel pitch.

The FPAs are integrated in compact dewar cooler configurations using different kinds of cooler types, like AIM's split linear coolers SX095 or SX040 or rotary integral types depending whatever fits best to the application.

The paper will present the development status and performance results of AIM's latest improved MCT LWIR Modules.

9451-77, Session 17

Low-dark current p-on-n MCT detector in long and very long-wavelength infrared

Cyril Cervera, Nicolas Baier, Olivier Gravrand, Olivier Boulade, Laurent Mollard, Commissariat à l'Énergie Atomique (France); Gérard Destéfanis, CEA-LETI (France); Vincent Moreau, Jean-Paul Zanatta, Commissariat à l'Énergie Atomique (France)

In this paper, we report on results obtained at CEA on p-on-n HgCdTe Infra-Red Focal Plane Arrays (IR FPAs) for the Long-wave (LW) and the Very-long-wave (VLW) spectral ranges. For many years, p-on-n arsenic-ion implanted planar technology has been developed and improved within the framework of the joint laboratory DEFIR[1][2]. This technology presents lower dark current and lower serial resistance in comparison with n-on-p architecture and is well adapted for low flux detection or high operating temperature.

This architecture has been evaluated for space applications in LWIR and VLWIR spectral bands with cutoff wavelengths from 10µm up to 15µm at 78K[3]. From these results, innovations have been introduced to the technological process to lower dark current at low temperature. This has been performed by decreasing the transition temperature from diffusion limited to generation-recombination limited dark current.

Other developments tend to improve the modulation transfer function (MTF). Large diffusion length which characterizes low doped n-type HgCdTe affect MTF, as optical cross-talk between pixels may be important. An evolution of the process has been brought to lower this cross-talk to improve MTF.

Electro-optical characterizations on p-on-n photodiodes have been performed on test arrays on individual photodiodes and on half-VGA format FPAs with 25µm and 30µm pixel pitches. Obtained results will be presented and discussed by focusing on the behavior at low temperature (Dark-current and MTF).

9451-79, Session 18

An IR journey *(Invited Paper)*

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

No Abstract Available

9451-80, Session 18

An IR castle *(Invited Paper)*

Gérard Destéfanis, CEA-LETI (France)

No Abstract Available

9451-81, Session 19

Reducing pixel geometries with MOVPE grown MCT arrays

R. Kennedy McEwen, David Jeckells, Sudesh K. Bains, Selex ES (United Kingdom)

The fabrication of high performance infrared detectors using mercury cadmium telluride (MCT) grown on GaAs substrates by Metal Organic Vapour Phase Epitaxy (MOVPE) is now an established mature production process at Selex ES. Recent years have seen a substantial reduction in MCT pixel sizes, driven by system requirements for increased resolutions, lower power consumption and reduced costs. From initial devices with 30µm pixels, previous developments have produced MOVPE grown MCT arrays of 24µm, 20µm and 16µm pixels with response in long, mid and dual wavebands (LWIR, MWIR & DWIR). High definition (HD) format and multi-megapixel arrays of 12µm MWIR pixels have also been produced using MOVPE grown MCT. The mesa structure of MOVPE grown MCT pixels inherently controls optical scattering, inter-pixel cross-talk, carrier diffusion and other blurring defects to negligible levels. This allows the goal for pixel size reduction to ultimately be determined by optical diffraction and Nyquist-Shannon sampling criteria alone.

This paper discusses the development of a new MCT detector at Selex ES, introducing the next generation of small pixels, towards this ultimate goal. Transition to smaller silicon design rules has enabled the pixel size reduction in the read-out integrated circuit (ROIC) to be achieved with minimum sacrifice of storage capacity. The ROIC has a completely digital control with on-chip digital generation of photodiode bias voltage. Low power proximity electronics providing a fully digitised output have been developed to ease interface with the detector. Characteristics of the pixel design together with

measured performance of the detector and its application to infrared sensor development, including updates of standard definition (SD) products to HD and better performance, will be addressed in the paper.

9451-82, Session 19

Update on 10μm pixel pitch MCT-based focal plane array with enhanced functionalities

Yann Reibel, Thibault Augey, Laurent Baud, Nicolas Péré-Laperne, Julien Roumegoux, Laurent Rubaldo, Olivier Pacaud, SOFRADIR (France)

Sofradir was first to show a 10μm FPA in DSS 2012, and announced the DAPHNIS 10μm product family back in DSS 2014. This pitch is a key, enabling more compact sensors and increased resolution. SOFRADIR recently achieved outstanding MTF demonstration at this pixel pitch, which even emphasizes the benefit to the users to adopt those new 10μm pixel pitch focal plane array based detectors. Those results, and associated gain in range, are discussed in this paper.

Concurrently to pitch downsizing, SOFRADIR also work on a global offering based on digital interfaces and smart pixel functionalities. This opens the way to reach enhanced functionalities such as improved image quality, higher frame rate, lower power consumption and optimum operation for wide thermal conditions scenes. This paper also discusses those enhanced features and how they come with strategies allowing an easier integration of the detector in the customer system.

9451-83, Session 19

Small pixel oversampled focal plane arrays *(Invited Paper)*

John T. Caulfield, Jerry A. Wilson, Cyan Systems (United States); Nibir K. Dhar, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Recently, imaging systems using smaller sub diffraction sized pixels have shown good imaging results. 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 5 micrcon pixel ROIC/IRFPA 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.

Cyan has recently tested the new HD format small ROICs and tests exhibited high yield. 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. Cyan is fabricating small pitch focal plane arrays and will demonstrate the first ever high definition IR data of 5 micron pitch MWIR sensors. We will review the phenomena of reducing pixels size has on improving Noise Equivalent Power. We will demonstrate the small pixel imagers capabilities in using temporal and spatial oversampling that effectively increases the SNR typically lost with smaller pixels. Other critical performance data such as NEDT, Uniformity, and Operability will be summarized.

9451-84, Session 20

Hardware acceleration of lucky-region fusion (LRF) algorithm for high-performance real-time video processing

Tyler Browning, Christopher R. Jackson, Furkan Cayci, Univ. of Delaware (United States); Gary W. Carhart, Jony J. Liu, U.S. Army Research Lab. (United States); Fouad E. Kiamilev, Univ. of Delaware (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 from fast, high-resolution image sensors, and fuses the sharp regions into a final, improved image. In our previous research, the LRF algorithm had been implemented on CPU and field programmable gate array (FPGA) platforms. The CPU did not have sufficient processing power to handle real-time processing of video. Last year, we presented a real-time LRF implementation using an FPGA. However, due to the slow register-transfer level (RTL) development and simulation time, it was difficult to adjust and discover optimal LRF settings such as Gaussian kernel radius and synthetic frame buffer size. To overcome this limitation, we implemented the LRF algorithm on an off-the-shelf graphical processing unit (GPU) in order to take advantage of built-in parallelization and significantly faster development time. Our initial results show that the GPU implementation has almost comparable turbulence mitigation to the FPGA version. In our presentation, we will explore optimization of the LRF algorithm on the GPU to achieve higher performance results, and adding new performance capabilities such as image stabilization and color.

9451-85, Session 20

Demonstrations of compressive pixel-based on-chip coded aperture temporal imaging of multiple and dynamic unresolved targets *(Invited Paper)*

Christy Fernandez-Cull, Brian M. Tyrrell, Joseph H. Lin, Richard D'Onofrio, MIT Lincoln Lab. (United States)

This paper reports on demonstrations with modified MIT Lincoln Laboratory digital-pixel focal plane array (DFPA) designs with advanced per-pixel processing capabilities for unresolved and resolved target temporal super resolution. We compare and contrast existing infrared (IR) DFPA global space-time filtering for single frequency discrimination in a single readout with our local space-time filtering approach combined with compressive-based processing. On-chip local space-time filtering transfers optical isomorphic image-plane-encoding to the focal plane array thereby removing diffraction and signal-to-noise ratio losses. Our hardware and approach enables on chip temporal discrimination of diverse and dynamic targets orders of magnitude faster than the readout frame rate, thereby allowing us to break the barriers associated with the conventional tradeoff between resolution and frame rate yielding a more agile and adaptive solution for target frequency-based identification and track. This work presents experimental data from arbitrary waveform modulated laser sources, both resolved and unresolved, at kHz to MHz frequencies recorded by a baseline single pixel high frame rate photodiode and two digital readout-integrated circuits (ROICs) hybridized to InGaAs two-dimensional detector arrays. We use digital ROICs capable of up to a 6 kHz global frame rate with up to 100 MHz per-pixel shuttering, where each pixel is modulated by a time-varying, pseudo-random, and duo-binary signal (+1,1,0). This paper shows 3D (x,y,t) temporal super-resolution from 2D-encoded projections of resolved and unresolved multi-target experimental data collected from our digital ROICs. We employ a compressive sensing framework leveraging recovery speed and improvements associated with total-variation regularization. Finally, we assess the compressibility, target size, target frequency, and noise

versus data recovery using linear and nonlinear data recovery approaches. Our digital ROICs demonstrate the potential for multi-target and multi-frequency discrimination in a single detector readout by implementing per-pixel shuttering and greater than two counters per pixel.

9451-105, Session 20

HD 1920 x 1080 digital ROICs for advanced IR sensor technologies

John T. Caulfield, Jon Paul Curzan, Cyan Systems (United States); Kenton T. Veeder, Nishant Dhawan, Senseeker Engineering Inc. (United States)

No Abstract Available

9451-88, Session 21

Resonator-QWIP FPA development *(Invited Paper)*

Kwong-Kit Choi, Jason N. Sun, Kimberley A. Olver, U.S. Army Research Lab. (United States)

Recently, we adopted the resonator-QWIPs to increase QE and observed values between 30 - 40% in FPAs. In this work, we performed a systematic optimization of the design using rigorous electromagnetic modeling. The objective is to improve FPA sensitivity, NETD, integration time, Tint, and operating temperature, T. The optimization variables are the doping density, Nd, and the number of QWs, Nq, while T is kept at 77 K. For 25 micron pixel pitch, 10 Me- integrated charge, and F/2 optics, the model predicts NETD = 19 mK at Tint = 1.43 ms for 9.2 micron cutoff. The NETD is larger at 24 mK at 0.59 ms for 10.2 micron cutoff. For 12 micron pitch, 6.8 Me- integrated charge, and F/2 optics, NETD = 24 mK at 2.2 ms for 9.2 micron cutoff. For 6 micron pitch, 6.8 Me- integrated charge, and F/1 optics, NETD = 19 mK at 4.0 ms for 9.0 micron cutoff, and it is 25 mK at 4.3 ms for 10.5 micron cutoff. Experimentally, we have investigated single R-QWIP detectors with 9.2 micron cutoff, Nd = 1E18/cm3, and Nq = 17 and 6; and detectors with 10.5 micron cutoff, Nd = 0.5E18/cm3, and Nq = 19 and 8. We have also fabricated FPAs with different pixel pitches from 6 to 30 microns and formats from 256 x 256 to 1920 x 1080. Their characteristics and performance will be reported if they become available.

9451-89, Session 21

Thermal infrared sensors at the Jet Propulsion Laboratory: hyperspectral and multispectral remote sensing

William R. Johnson, Simon J. Hook, Jet Propulsion Lab. (United States)

The Jet Propulsion Laboratory is now actively flying the Hyperspectral Thermal Emission Spectrometer (HyTES) on various science campaigns. It records 256 spectral channels in the long wave infrared at low altitude (1K to 3K meters AGL) with a wide 50-degree imaging field of view. It's also being modified to allow sub-orbital flights on NASA's ER-2 platform. Results from recent low altitude flights are discussed along with design modifications needed to fly on the ER-2.

JPL is also actively working on the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS). It will be the first thermal infrared instrument on the space station and will allow unprecedented high spatial resolution in 5 thermal infrared spectral channels over a wide swath. Due to the space station orbit, it will have a temporal repeat similar to MODIS but with sampling throughout the diurnal cycle, and spectral coverage similar to ASTER. This optimal combination of attributes enables the advancement of the science objectives not addressable with NASA's current missions. The instrument requirements are described in general terms along with current testing results from the engineering model.

9451-90, Session 21

Theoretical study of QWIP or QDIP IR-FPA non-uniformity correction

Yusuke Matsukura, Fujitsu Labs., Ltd. (Japan)

Infrared focal plane array (IR-FPA), which construct infrared image using two dimensionally arrayed infrared detector pixels, is useful tool in many field such as security or infrastructure monitoring, vegetation survey, medical inspection, and so on.

Non-uniformity correction (NUC), which makes the IR-FPA pixel output to be the same with each other, electronically, for the same IR incidence, is indispensable technique because it is, if not impossible, very difficult to fabricate the FPA pixel sufficiently uniform. There have been many researches that are dedicated to the improvement of NUC quality. However, intrinsic (due to the device) and/or extrinsic (due to the electronics) nonlinearity still impose some difficulty upon the NUC.

In our presentation, we first derive the formula that can successfully describe the device nonlinearity between the IR incidence corresponding to the blackbody temperature T and the pixel output V for the infrared detectors such as QWIPs (Quantum Well Infrared Photodetectors) or QDIPs (Quantum Dot Infrared Photodetectors), which has peak (not cutoff) type photo response.

Secondary, using this formula, we show that, in theory, conventional "two-point correction" can completely correct the non-uniformity, therefore, in the case of QWIP- or QDIP-FPA, the origin of the NUC incompleteness, that is, the origin of the residual non-uniformity in the IR image, is the nonlinear input-output (I/O) characteristics in the electronics.

Lastly, we show that the I/O nonlinearity in the electronics can be corrected using our formula to reconstruct the completely non-uniformity corrected IR image.

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9452-1, Session 1

Black-box imager characterization, from measurements to modeling range performance *(Invited Paper)*

David P. Haefner, Stephen D. Burks, Brian P. Teaney, U.S. Army RDECOM CERDEC NVESD (United States)

This talk outlines the process of transitioning from measured values to modeled performance employed by NVESD in the Advanced Sensor Evaluation Facility (ASEF). We discuss the details of the measurement process in terms of the assumptions that have to be made and how they affect the end result. We also detail how measurement and sampling errors can be included by using confidence intervals, which in turn enables comparisons from lab to lab to be made. Some of the topics under review will include: Pixel level SiTF or Photon Transfer, sample corrected 3D Noise with confidence intervals, sampling determination from projected bar targets, FOV calculation from an assumed projection, MTF for scanning systems, and MTF with defective pixels. Although some change in hardware is typically required, the techniques and procedures discussed can be applied to both emissive and reflective band sensors. We will conclude with the main output of objective measurements, a system model, which can then be used for performance modeling (for example in NV-IPM) of situations beyond those examined in the laboratory.

9452-2, Session 1

Characterizing a high-resolution CRT display performance using a Prichard photometer with microscanner

Balvinder Kaur, Jeff T. Olson, Jonathan G. Hixson, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Measuring the performance of a cathode ray tube (CRT) display is necessary to enable end-to-end system modeling and measurement of currently used high performance analog imaging systems, such as 2nd Generation FLIR systems. If the CRT is a color CRT or high resolution monochrome CRT, the performance measurements are made more difficult because of the underlying structure of the pixel as compared to a low resolution monochrome pixel. Out of the various characteristics of interest, we focus on determining the gamma value and MTF of a display. Gamma quantifies the non-linear response between the gray scale and the displayed luminance. MTF quantifies the displayed image degradation based on the blur, contrast, noise, bandwidth, and signal metrics. If the displayed image can be corrected for the CRT's gamma and MTF, an accurate scene can be presented or characterized for laboratory measurements such as MRT (Minimum Resolvable Temperature) and CTF (Contrast Threshold Function). In this paper, we present a method to determine the gamma and MTF to characterize a color CRT display using the Prichard 1980A photometer with the SC-80A microscanner attachment. Gamma corrections were applied to the test images for validating the accuracy of the computed gamma value. MTFs were computed based on measurements made with various aperture sizes and corrected for the aperture size. The method presented here is a simple one, easily implemented employing a Prichard photometer. An analogous method for flat panel displays will also be commented on.

9452-3, Session 1

Validating machine vision MRT performance against trained observer performance for linear shift invariant sensors

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

Researchers at the US Army Night Vision and Electronic Sensors Directorate have added the functionality of Machine Vision MRT (MV-MRT) to the NVLabCap software package. While the original calculations of MV-MRT were compared to human observer's performance using digital imagery in a previous effort, the technical approach was not tested on 8-bit imagery using a variety of sensors in a variety of gain and level settings. Now that it is relatively simple to calculate the MV-MRT for a given sensor in multiple states, it is prudent to compare the results of MV-MRT in multiple sensor states to the performance of human observers for thermal imaging systems that are linear and shift invariant. The comparison of the results for multiple MWIR and LWIR systems to trained human observers are presented.

9452-4, Session 1

Advanced E-O test capability for Army Next-Generation Automated Test System (NGATS)

Fred King, Steve Errea, Gregory P. Matis, Steve W. McHugh, James McKechnie, Brian Nehring, Santa Barbara Infrared, Inc. (United States)

The Next Generation Automatic Test System (NGATS) is a reconfigurable, general-purpose, mobile, deployable, automated test system developed to provide off-platform sustainment support to all U.S. Army weapon systems. The Future E-O (FEO) program was established to meet the Army's need for a flexible, modular, automated test capability as part of NGATS to support the test and diagnostic needs of current fielded Army electro-optical (E O) devices, as well as being expandable to address the requirements of future military EO systems. The "smart module" philosophy implemented in the FEO system design will provide significant reductions in the cost of periodic calibration and ease of maintenance.

The FEO system - in addition to its extensive test and evaluation capabilities for MWIR, LWIR and visible/low-light-level imaging sensors - is also capable of testing a wide range of key performance characteristics for systems incorporating laser rangefinders and/or designators.

In addition to presenting a detailed overview of the FEO hardware design, features and testing capabilities, the paper will also describe how SBIR's IR/EO sensor test software package, IRWindows™4, has been integrated to automate the test execution, data collection, and analysis, archiving and reporting of results.

9452-5, Session 1

Signal intensity transfer function determination on thermal systems with stray light and scattering present

Stephen D. Burks, U.S. Army Night Vision & Electronic

Sensors Directorate (United States)

Accurate Signal Intensity Transfer Functions (SITF) measurements are necessary to determine the calibration factor in the 3D noise calculation of an electro-optical imaging system. The typical means for measuring a sensor's SITF is to place the sensor in a flooded field environment at a distance that is relatively close to the aperture of the emitter. Unfortunately, this arrangement has the potential to allow for additional contributions to the SITF in the form of scattering and stray light if the optics are not designed properly in the system under test. Engineers at the US Army Night Vision and Electronic Sensors Directorate have come up with a means of determining the contribution due to scatting and stray light, and show their contribution to the SITF for a variety of systems that have come to NVESD for testing.

9452-6, Session 1

Measuring noise equivalent irradiance of a digital short-wave infrared imaging system using a broadband source to simulate the night spectrum

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

There is a growing interest in developing helmet-mounted digital imaging systems (HMDIS) for integration into military aircraft cockpits. This interest stems from the multiple advantages of digital vs. analog imaging such as image fusion from multiple sensors, data processing to enhance the image contrast, superposition of non-imaging data over the image, and sending images to remote location for analysis.

There are several properties an HMDIS must have in order to aid the pilot during night operations. In addition to the resolution, image refresh rate, dynamic range, and sensor uniformity over the entire Focal Plane Array (FPA); the imaging system must have the sensitivity to detect the limited night light available filtered through cockpit transparencies. Digital sensor sensitivity is generally measured monochromatically using a laser with a wavelength near the peak detector quantum efficiency, and is generally reported as either the Noise Equivalent Power (NEP) or Noise Equivalent Irradiance (NEI).

This paper proposes a test system that measures NEI of Short-Wave Infrared (SWIR) digital imaging systems using a broadband source that simulates the night spectrum. This method has a few advantages over a monochromatic method. Namely, the test conditions provide spectrum closer to what is experienced by the end-user, and the resulting NEI may be compared directly to modeled night glow irradiance calculation. This comparison may be used to assess the Technology Readiness Level of the imaging system for the application. The test system is being developed under a Cooperative Research and Development Agreement (CRADA) with the Air Force Research Laboratory.

9452-7, Session 1

Statistical analysis of target acquisition sensor modeling experiments

Dawne M. Deaver, Steven K. Moyer, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The US Army RDECOM CERDEC NVESD Modeling and Simulation Division is charged with the development and advancement of military target acquisition modeling to estimate expected soldier performance when using all types of imaging sensors. Two elements of sensor performance modeling are: (1) laboratory-based psychophysical experiments used to measure task performance and calibrate the various models and (2) field-based experiments used to confirm the model estimates for specific sensors. In both types of experiments, it is common practice to control or measure environmental, sensor, and target physical parameters in order to minimize uncertainty of the modeling. Predicting the minimum number of test subjects required to calibrate or validate the model should be, but is not always, done during test planning. The objective of this analysis is to develop guidelines that recommend the number and types of test samples required to yield a statistically significant result. Hypothesis testing, sample size justification, and experimental power calculations are applied to a sample target acquisition task, and a determination of statistical significance is reported.

9452-8, Session 1

Panoramic sensor requirements for military vehicles

Orges Furxhi, Ronald G. Driggers, St. Johns Optical Systems (United States); Bradley L. Preece, Keith A. Krapels, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Panoramic infrared imaging is relatively new and has many applications to include tower mounted security systems, shipboard protection, and platform situational awareness. In this paper, we review the requirements for an infrared panoramic imaging system for military vehicles. We begin with a broad view of military requirements organized into three categories, survivability, mobility, and lethality. The requirements for the sensor modes of operation across all categories are ranked so that panoramic system design can address as many needs as possible, but with affordability applied to system design. These military requirements are translated into panoramic imager requirements by parameterizing the characteristics of the scene and other typical sensor parameters that are independent of panoramic imaging. The paper presents these requirements as well as potential design strategies that result in comprehensive and affordable solutions.

9452-9, Session 2

Simulation of a polarized laser beam reflected at the sea surface: modeling and validation

Frédéric Schwenger, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

A 3D simulation of the polarization-dependent reflection of a Gaussian shaped laser beam on the dynamic sea surface is presented. The simulation considers polarized or unpolarized laser sources and calculates the polarization states upon reflection at the sea surface. It is suitable for the pre-calculation of images for cameras operating in different spectral wavebands (e.g. near-infrared). The simulation also considers a bistatic configuration of laser source and receiver as well as different atmospheric conditions. In the near-infrared, the detected total power of reflected laser light is compared with data collected in a field trial.

Our computer simulation combines the 3D simulation of a maritime scene (open sea/clear sky) with the simulation of polarized or unpolarized laser light reflected at the sea surface. The basic sea surface geometry is modeled by a composition of smooth wind driven gravity waves. To predict the view of a camera equipped with a linear polarizer, the polarized sea surface radiance must be calculated for the specific waveband. The s- and p-polarization states are calculated for the emitted sea surface radiance and the specular reflected sky radiance to determine the total polarized sea surface radiance of each component. The states of polarization and the radiance of laser light specularly reflected at the wind-roughened sea surface are calculated by considering the s- and p- components of the electric field of laser light with respect to the specular plane of incidence. This is done by using the formalism of their coherence matrices according to E. Wolf. Additionally, an analytical statistical sea surface BRDF (bidirectional reflectance distribution function) is considered for the reflection of laser light radiances.

Validation of the simulation results is required to ensure model credibility

and applicability to maritime laser applications. For validation purposes, field measurement data (images and meteorological data) was analyzed. A near-infrared laser, with or without a mounted polarizer, produced laser beam reflection at the water surface and images were recorded by a camera equipped with a polarizer with horizontal or vertical alignment. The validation is done by numerical comparison of measured total laser power extracted from recorded images with the corresponding simulation results. The results of the comparison are presented for different incident (zenith/azimuth) angles of the laser beam and different alignment for the laser polarizers (vertical/horizontal/without) and the camera (vertical/horizontal).

9452-10, Session 2

Detector integration time-dependent atmospheric turbulence imaging simulation

Todd W. Du Bosq, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Endre Repasi, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Atmospheric turbulence is a well-known phenomenon that often degrades image quality due to intensity fluctuations, distortion, and blur in electro-optic and thermal imaging systems. To properly assess the performance of an imaging system over the typical turbulence trade space, a time consuming and costly field study is often required. A fast and realistic turbulence simulation will allow the performance assessment of an imaging system under various turbulence conditions to be done as well as provide input data for the evaluation of turbulence mitigation algorithms in a cost efficient manner.

The simulation is based on an empirical model with parameters derived from the first and second-order statistics of imaging distortions measured from field collected data. The dataset consists of image sequences recorded with a variable frame rate visible camera at strong and weak turbulence conditions. The simulation uses pristine, single images containing no turbulence effects as an input and produces image sequences degraded by the specified turbulence. Target range, optics diameter, wavelength, detector integration time, and the wind velocity component perpendicular to the propagation path all contribute to the severity of the atmospheric turbulence distortions and are included in the simulation. The addition of the detector integration time expands the functionality of the simulation tool to include imagers with lower frames rates. Examples are presented demonstrating the utility of the turbulence simulation.

9452-12, Session 2

Automatic parameter estimation for atmospheric turbulence mitigation techniques

Stephen Kozacik, Aaron L. Paolini, Eric J. Kelmelis, EM Photonics, Inc. (United States)

Several image processing techniques for turbulence mitigation have been shown to be effective under a wide range of long-range capture conditions; however, complex, dynamic scenes have often required manual interaction with the algorithm's underlying parameters to achieve optimal results. While this level of interaction is sustainable in some workflows, in-field determination of ideal processing parameters greatly diminishes usefulness for many operators. Additionally, some use cases, such as those that rely on unmanned collection, lack human-in-the-loop usage.

To address this shortcoming, we have extended a well-known turbulence mitigation algorithm based on bispectral averaging with a number of techniques to greatly reduce (and often eliminate) the need for operator interaction. Automations were made in the areas of turbulence strength estimation (Fried's parameter), as well as the determination of optimal local averaging windows to balance turbulence mitigation and the preservation of dynamic scene content (non-turbulent motions).

These modifications deliver a level of enhancement quality that approaches that of manual interaction, without the need for operator interaction. As a consequence, the range of operational scenarios where this technology is of benefit has been significantly expanded.

9452-13, Session 2

Atmospheric turbulence and sensor system effects on biometric algorithm performance

Richard L. Espinola, Kevin R. Leonard, U.S. Army RDECOM CERDEC NVESD (United States); Kenneth A. Byrd, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Guy Potvin, Defence Research and Development Canada, Valcartier (Canada)

Biometric technologies composed of electro-optical/infrared sensor systems and advanced matching algorithms are being used in various force protection/security and tactical surveillance applications. To date, most of these sensor systems have been widely used in controlled conditions with varying success (e.g., short range, uniform illumination, cooperative subjects). However the limiting conditions of such systems have yet to be fully studied for long range applications and degraded imaging environments. Biometric technologies used for long range applications will invariably suffer from the effects of atmospheric turbulence degradation. Atmospheric turbulence causes blur, distortion and intensity fluctuations that can severely degrade image quality of electro-optic and thermal imaging systems and, for the case of biometrics technology, translate to poor match algorithm performance. In this paper, we evaluate the effects of atmospheric turbulence and sensor resolution/noise on biometric matching algorithm performance. We use a subset of the Facial Recognition Technology (FERET) database and various commercial and research algorithms to perform the analyses on turbulence degraded facial images to obtain match performance. The goal of this work is to understand the feasibility of long-range facial recognition in degraded imaging conditions, and the utility of camera parameter trade studies to enable the design of the next generation biometrics sensor systems.

9452-14, Session 2

An adaptive tracker for ShipIR/NTCS

Srinivasan Ramaswamy, David A. Vaitekunas, W. R. Davis Engineering, Ltd. (Canada)

A key component in any image-based tracking system is the adaptive tracking algorithm used to segment the image into potential targets, rank-and-select the best candidate target, and the gating of the selected target to further improve tracker performance. This paper will describe a new adaptive tracker algorithm added to the naval threat countermeasure simulator (NTCS) of the NATO-standard ship signature model (ShipIR). The new adaptive tracking algorithm is an optional feature used with any of the existing internal NTCS or user-defined seeker algorithms (e.g., binary centroid, intensity centroid, and threshold intensity centroid). The algorithm segments the detected pixels into clusters, and the smallest set of clusters that meet the detection criterion is obtained using a knapsack algorithm to identify the set of clusters that should not be used. The rectangular area containing the chosen clusters defines an inner boundary, from which a weighted centroid is calculated as the aim-point. A track-gate is then positioned around the clusters, taking into account the rate of change of the bounding area and compensating for any gimbal displacement. A sequence of scenarios is used to test the new tracking algorithm on a generic unclassified DDG ShipIR model.

9452-38, Session PSTue

New night vision goggle gain definition

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

A new definition is proposed for the calibration of Night Vision Goggle (NVG) gains. This definition is based on the measurement of radiometric input and output quantities of the NVG. While the old definition used the “equivalent fL” which is a non SI traceable luminance unit, the new definition utilizes the radiance quantities that are traceable to the SI units through NIST standards. The new NVG gain matches the previous one as a result of the application of a correction coefficient originating from the conversion of the radiance to luminance units. The new definition was tested at the NIST Night Vision Calibration Facility and the measurement results were compared to the data obtained with a Hoffman Test Set Model ANV-126. The tests also included the calibration issue of the internal luminance meter of the Test Set and the radiance and luminance set points of the ANV-126 Test Set that define the measured NVG gain. Comparing the radiometric quantities at the Hoffman Test Set and those measured by the NIST transfer standard radiometer, indicates that the observed differences up to 15% were due to the calibration and experimental errors of the ANV-126 Test Set. In view of different spectral characteristics of luminophores that can be utilized in the NVG design, the simulation of the NVG output for gain measurement was performed. The NVG output was simulated with a sphere-based source with different LEDs and the measured gain was compared to that obtained with the internal ANV-126 luminance meter. The NVG gain uncertainty analysis was performed for the Type A, B, and C goggles. An additional uncertainty component due to the no-moon night sky illumination was also analyzed.

9452-39, Session PSTue

Application and validation of a S/W developed for IR signal simulation by using the measured data from a moving test ship

Kuk-Il Han, Dong-Geon Kim, Jun-Hyuk Choi, Tae-Kuk Kim, Chung-Ang Univ. (Korea, Republic of)

Infrared signals are widely used to detect or discriminate objects against the background. Direct measurements of the infrared signals from objects under various operating conditions are cost ineffective and time consuming works and the computer simulation method is developing rapidly to replace or supplement those experimental tasks. The IR signal detected by a sensor can be divided into three components: the self-emitted radiance, the radiance coming out after being reflected on the surface from the external radiation sources, the radiance not related to the object that is generated by the atmosphere. In this study, we developed an IR image generation S/W by considering these three IR signal components to be applied for moving objects. To validate the S/W developed here the IR signal and the surface temperature are measured from a test ship(displacement: 1,200 tons, length: 65.4 meters, width: 12.4 meters) operating along a designated route on the sea, and the weather conditions and the ship positions are also measured simultaneously. Calculation of the surface temperature profile of the test ship is performed by using the S/W developed in this study with the three-dimensional modeling of the test ship subdivided into 41,000 meshes and the corresponding IR image is generated into 640x512 pixels. Calculations of the surface temperature and the IR signal level are performed by using the measured weather data obtained during the experiments. Results of the surface temperature and the IR signal obtained from the measurement and the numerical analysis show fairly good agreements and we found an applicability of the developed S/W in analyzing IR signals from moving objects

9452-40, Session PSTue

Contrast performance modeling of broadband IR imaging systems with tunable filter fore-optics

Van A. Hodgkin, U.S. Army RDECOM CERDEC NVESD (United States)

Most mass-produced, commercially available and fielded military infrared (IR) imaging systems operate across broad swaths of the near infrared (NIR), shortwave infrared (SWIR), or thermal infrared (TIR) wavebands without any spectral selectivity within those wavebands. In imaging applications that employ these systems, it is not uncommon to be imaging a scene in which the image contrasts between the objects of interest, i.e., the targets, and the objects of little or no interest, i.e., the backgrounds, are sufficiently low to make target discrimination difficult and uncertain. This can occur even when the spectral distribution of the target and background signatures across the given waveband differ significantly from each other, because the fundamental components of image contrast are the spectral integrals of the target and background signatures. Spectral integration in the detectors tends to smooth out any differences. Hyperspectral IR imaging is one approach to preserving, and thus highlighting, spectral differences across the scene, even when the waveband integrated signatures would be about the same, but it is an expensive, complex, noncompact solution and generally not timely. This paper documents a study of how the capability to selectively customize the spectral width and center wavelength would allow a broadband IR imaging sensor to customize image contrast as a function of scene content and ambient illumination.

9452-41, Session PSTue

A real-time contrast enhancement using adaptive histogram threshold for a FLIR camera

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Recently, forward looking infrared (FLIR) cameras are being deployed over the world to protect important public facilities. In order to make FLIR camera small and reasonable price, the camera does not have enough computing power to process FLIR images. Thus, it is very important to develop a real-time image processing algorithm. We present, in this paper, a real-time contrast enhancement method for a FLIR camera by using adaptive histogram threshold and redistribution. In the FLIR imaging system, histogram equalization (HE) is generally used for contrast enhancement. Since the HE approach causes significant change in brightness, it results in the washed-out appearance and false contouring. Another approach, dynamic range separate histogram equalization (DRSHE), enhances the image contrast by separating the dynamic range of histogram into k parts, but the scale factor is static and manually configured. Therefore, the approach cannot be used for real-time imaging system since the scale factor should be adjusted to a real surveillance environment. In order to resolve the problem, we proposed an adaptive histogram threshold mechanism and redistribution based on the histogram partition. We evaluate lots of different environment by using our FLIR camera to acquire dynamic histogram threshold. We conclude the iteration threshold for separating histogram is 3 for an indoor environment and 4 for an outdoor environment since the image quality is almost converged on a certain threshold. Results on the video sequences showed that the proposed method can enhance video quality irrespective of indoor and outdoor environment due to the dynamic histogram threshold.

9452-42, Session PSTue

Optical design of an LWIR imaging polarimetric camera

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Imaging polarimetry has been a topic of research for almost two decades and still new concepts in the field emerge. It has proven to be an attractive means of detection for man-made objects against non-polarized scene or in SAR operations for man detection against polarized water surface. Different spectral bands are used and different approaches to the architecture are utilized. Among well-known solutions that of division of amplitude, division of aperture and division of time are most common in literature. Although general idea of a rotating polarizer architecture is well known a new approach to this architecture is proposed. In the article an optical design of a two-detector, division of amplitude LWIR (8 -14 ?m) polarimeter is discussed that combines approaches used in division of amplitude and division of time architectures. The novelty of the design lays in that the polarizer in the measurement arm of the camera is being rotated at a constant speed (unlike in division of time, rotating polarizer architecture) and the polarimetric Stoke's parameters are calculated from harmonic intensity variations in registered image.

Lacking retarding element the said polarimeter is of the incomplete type, i.e. it measures S0, S1 and S2 components of the Stoke's vector. Since rotating polarizer design is mechanically more complicated than most other architectures the optical design is discussed along with mechanical considerations that affect optical parameters and performance of the final design. Bearing selection, critical tolerances of mechanical and optical design and final alignment procedure is discussed.

9452-15, Session 3

Simulation-based sensor modeling and at-range target detection characterization with MuSES *(Invited Paper)*

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Accurate infrared signature prediction of targets, such as humans or ground vehicles, depends primarily on the realistic prediction of physical temperatures. Thermal model development typically requires a geometric description of the target (i.e., a 3D surface mesh) along with material properties for characterizing the thermal response to simulated weather conditions. Once an accurate thermal solution has been obtained, signature predictions for an EO/IR spectral waveband can be generated. The image rendering algorithm should consider the emissions, diffuse/specular reflections, and atmospheric effects to depict how an object in a natural scene would be perceived by an EO/IR sensor.

The EO/IR rendering process within MuSES (ThermoAnalytics, Inc.) can be used to create a synthetic radiance image that predicts the energy detected by a specific sensor just prior to passing through its optics. For additional realism, blurring due to lens diffraction and noise due to variations in photon detection can also be included, via specification of sensor characteristics. Additionally, probability of detection can be obtained via the Targeting Task Performance (TTP) metric, making it possible to predict a target's at-range detectability to a particular threat sensor. In this paper, we will investigate the at-range contrast and detectability of some example targets and examine the effect of various techniques such as sub-pixel sampling and target pixel thresholding.

9452-16, Session 3

Probability of detection using ShipIR/NVIPM

David A. Vaitekunas, W. R. Davis Engineering, Ltd. (Canada); Gerald C. Holst, JCD Publishing (United States); Srinivasan Ramaswamy, W. R. Davis Engineering, Ltd. (Canada)

Existing FLIR detection models such as NVThermIP and VN-IPM, from the U.S. Army Night Vision and Electronic Sensors Directorate (NVESD), use only basic inputs to describe the target and background (area of the target, average and RMS temperatures of both the target and background). The objective of this work is to try and bridge the gap between more sophisticated FLIR detection models (of the sensor) and high-fidelity signature models, such as the NATO-Standard ShipIR model. A custom API is developed to load an existing ShipIR scenario model and perform the analysis from any user-specified range, altitude, and attack angle. The analysis consists of computing the total area of the target (m2), the average and RMS variation in target source temperature, and the average and RMS variation in the apparent temperature of the background. These results are then fed into the associated sensor model in NV-IPM to determine its probability of detection (versus range). Since ShipIR computes and attenuates the spectral source radiance at every pixel, the black body source and apparent temperatures are easily obtained for each point using numerical iteration (on temperature), using the spectral attenuation and path emissions from modtran (already used by ShipIR to predict the apparent target and background radiance). In addition to performing the above parameters on the whole target area, a variable threshold and clustering algorithm is used to analyse whether a sub-area of the target, with a higher contrast signature but smaller size, is more likely to be detected. The methods and results from this analysis should provide the basis for a more formal interface between the two models.

9452-17, Session 3

A TRM4 component for the night vision integrated performance model

Joseph P. Reynolds, Brian P. Teaney, U.S. Army RDECOM CERDEC NVESD (United States); Todd W. Du Bosq, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Endre Repasi, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

The Thermal Range Model (TRM4) developed by the Fraunhofer IOSB of Germany is a commonly used performance model for military target acquisition systems. There are many similarities between the U. S. Army, Night Vision Integrated Performance Model (NV-IPM) and TRM4. Almost all of the camera performance characterizations, such as signal to noise calculations and modulation transfer theory are identical, only the human vision model and performance metrics differ. Utilizing the new Custom Component Generator of NV-IPM we

develop a component to calculate the Amplitude Modulation at Optimal Phase (AMOP) and Minimum Temperature Difference Perceived (MTDP) calculations used in TRM4. The results will be compared with the actual TRM4 results for a variety of imaging system. This effort demonstrates that NV-IPM is a versatile system design tool and can easily be extended to include variety of image quality and performance metrics.

9452-18, Session 3

A low-light performance survey of commercially available camera modules

Bradley L. Preece, David M. Tomkinson, Joseph P.

Reynolds, U.S. Army RDECOM CERDEC NVESD (United States)

Using the latest models from Night Vision and Electronic Sensors Directorate (NVESD), a survey of monochrome and color low light level imaging systems is conducted. Each camera system is evaluated and compared with similar design constraints, including optics, field of view, dynamic range, as well as lighting conditions. Comparisons will use the V parameter of the Targeting Task Performance (TTP) metric within the latest version of the Night Vision Integrated Performance Model (NV-IPM). In addition, a detailed comparison between the performance of a Bayer color camera, a Bayer color camera with the near infrared block filter removed, the equivalent monochrome version of the camera, and an equivalent direct view optical systems is performed.

9452-19, Session 3

Depth of field in modern thermal imaging

Norbert Schuster, John W. Franks, Umicore Electro-Optic Materials (Belgium)

Modern thermal imaging lenses for uncooled detectors are high aperture systems. Very often, their aperture based f-number is faster than 1.2. The impact of this on the depth of field is dramatic, especially for narrow field lenses. The users would like to know how the image quality changes with and without refocusing for objects with at different distances from the camera core.

The RAYLEIGH approach to evaluate the depth of field is based on the un-aberrated Point Spread Function. It delivers a handy first order relation which cannot consider the actual lens resolution.

Classic Depth of Field approach supposes a certain allowed blur as circle of confusion. This blur has a certain relation to the Transfer Function of lens and of imaging device.

IR-system designers need a method which relates to real system measurements such as the lens MTF for different object positions. Our way to respect the camera core performance in a reasonable and handy way is to analyse the lens performance in terms of MTF at 50% Nyquist frequency. Then, the lens MTF-value of 0.5 characterizes the limit of Depth of Field. This criterion is a proven way for many applications.

The approach presented here is based on the Through Focus MTF. Several values of spatial resolution can be considered and the impact of imaging device is shown.

A convention for the Depth of Field and Focus Range based on the hyperfocal distance is proposed.

The approach is applied to different commercially available lenses, and the practical consequences for efficient use of lenses are deduced.

9452-20, Session 4

Optimum viewing distance *(Invited Paper)*

Gerald C. Holst, JCD Publishing (United States)

Human visual system (HVS) "resolution" varies with illumination level, target characteristics (Snellen letters, vernier acuity, checkerboard, etc.), and target contrast. Resolution is defined as the visual angle subtended by the eye: target size divided by viewing distance. Remarkably, the population has a resolution of approximately 1 arc minute for high contrast targets. For signage, computer displays, cell phones, and TVs a viewing distance and display size is selected. Then the number of display pixels is chosen to achieve 1 arc min. Resolution of low contrast targets is quite different. It is best described by Batrten's contrast sensitivity function (CSF). The CSF is broad suggesting that there is a range of "optimum" viewing distances. NVIPM predicts target acquisition range based upon the system MTF and CSF. The optimum viewing distance depends upon the display pixel size and system MTF. It is independent of magnification. As the system MTF degrades (e.g. due to optical aberrations), the optimum viewing distance changes. Likewise, as noise increases, viewing distance changes. Only monochromatic targets are considered.

9452-21, Session 4

Optimal design of a compressive sensing imaging system

Bradley L. Preece, U.S. Army RDECOM CERDEC NVESD (United States); Todd W. Du Bosq, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Nader M. Namazi, Georges T. Nehmetallah, The Catholic Univ. of America (United States)

The design and modeling of compressive sensing (CS) imagers is difficult due to the complexity and non-linearity of the system and reconstruction algorithm. The Night Vision Integrated Performance Model (NV-IPM) is a linear imaging system design tool that is very useful for complex system trade studies. The custom component generator, included in NV-IPM, will be used to include a recently published theory for CS that links measurement noise, easily calculated with NV-IPM, to the noise of the reconstructed CS image, given the sparsity of the scene and number of measurements as an input. As the sparsity will also depend on the optical transfer function, an empirical relationship will be developed between the linear model within NV-IPM and the non-linear reconstruction algorithm using human perception test data. Using the theory and relationship, a CS imager varying the number of measurements will be compared to a notional traditional imager.

9452-22, Session 4

Block randomization versus complete randomization of human perception stimuli: Is there a difference?

Steven K. Moyer, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Elizabeth R. Uhl, U. S. Army Research Institute (United States)

For more than 50 years, the U.S. Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate (NVESD) has been studying and modeling the human visual discrimination process as it pertains to military imaging systems. In 1998 NVESD created a program to help train Soldiers to identify combat vehicles. From 1998 until 2006 experimental stimuli were block randomized, meaning that stimuli with similar difficulty levels (for example, in terms of distance from target, blur, etc.) were presented together in blocks of approximately 24 images, but the order of images within the block was random. Starting in 2006, complete randomization of stimuli for human perception experiments came into vogue, meaning that difficulty changed image to image. A decrease in Soldier performance has been noted over the past 14 years. In this preliminary study we will investigate the impact of the two types of randomization on performance in two groups of observers, matched for skill to create equivalent groups. Soldiers in the block randomization condition are expected to perform better than Soldiers in the complete randomization group. It is hypothesized that Soldiers in the complete randomization condition will have to shift their criteria more frequently than Soldiers in the block randomization group, and this is expected to impede performance. Preliminary results suggest that block randomization may provide an advantage under certain conditions. These findings indicate that researchers examining visual perception tasks should take presentation order into consideration when designing a task.

9452-23, Session 4

Modeled performance of low-light digital imagers

Joseph P. Reynolds, Bradley L. Preece, U.S. Army RDECOM CERDEC NVESD (United States)

We present a model-based trade study of various digital imaging technologies as a possible upgrade to current image intensified night vision goggles (NVG). The study includes all forms of silicon-based CCD/CMOS, SWIR focal plane technology as a function of wavelength cutoff, and uncooled thermal imagers. System level performance comparisons will be made using a unity magnification design. Trades will be made over light level, target contrast, spectral response, dark current, read noise, and optical parameters. System comparisons use the Targeting Task Performance (TTP) metric within the latest version of the Night Vision Integrated Performance Model (NV-IPM).

9452-43, Session 4

Comparative performance of large-format MWIR and LWIR systems in NV-IPN

Edward M. Burdette, J. Ralph Teague, Georgia Tech Research Institute (United States); Christopher L. Dobbins, U.S. Army Redstone Technical Test Ctr. (United States); Samuel B. Wood, U.S. Army (United States)

This report describes tasks comparing the simulated performance levels of infrared (IR) sensing systems in detecting, recognizing, and identifying (DRI) targets using the Night Vision Integrated Performance Model (NV-IPM). Both mid-wave infrared (MWIR) and long-wave infrared (LWIR) systems, chosen to represent the current state-of-the-art, were analyzed across various environmental conditions. These states included a range of both man-made and natural obscurants, selected to simulate atmospheric conditions commonly experienced throughout the world. This report investigates the validity of the NV-IPM, down-selects top-performing systems from an original set, and provides detailed performance analysis of these best-of-breed systems in various environmental scenarios.

Six sensing systems, Indium-Antimonide (InSb) MWIR, Mercury-Cadmium-Telluride (MCT) MWIR, nBn InSb MWIR, Quantum Well Infrared Photodetector (QWIP) LWIR, uncooled LWIR, and dual-band MCT MWIR/LWIR system, were evaluated against a variety of environmental variations. Specifications for the IR systems were obtained from manufacturers or relevant published literature. Simulation results indicated the nBn InSb MWIR system as the strongest-performing system in many of the tests.

9452-24, Session 5

Legacy modeling and range prediction comparison: NV-IPM versus SSCamIP and NVTherm

Jonathan G. Hixson, Philip I. Richardson, Balvinder Kaur, David M. Tomkinson, Brian P. Teaney, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

NVESD's new integrated sensor performance model, NV-IPM, replaces the discrete spectral band models that preceded it (NVTherm, SSCamIP, etc.). Many advanced modeling functions are now more readily available, easier to implement, and integrated within a single model architecture. For the legacy model user with ongoing modeling duties, however, the conversion of legacy decks to NV-IPM, enabling the rapid transition to the resumption of making confident predictions, is of more immediate concern than mastering the many "power features" now available. This paper addresses the processes for the legacy model user to make a smooth transition to NV-IPM, including the conversion of legacy sensor decks to NV-IPM format decks, differences in parameters entered in the new vs. old model, and a comparison of the predicted performance differences between NV-IPM and legacy models. Examples are presented to demonstrate the ease of sensor deck conversion from legacy models and to highlight enhanced model capabilities available with minimal transition effort.

9452-25, Session 5

Custom component generation in the night vision integrated performance model

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The latest version of the Army imager performance models, the Night Vision Integrated Performance Model (NV-IPM), is now contained within a single system engineering oriented design environment. This new model interface allows sensor systems to be represented using modular, reusable components. A new feature, added in version 1.3 of the NV-IPM, enables users to create custom components which can be incorporated into modeled systems. The ability to modify existing component definitions and create entirely new components in the model hierarchy greatly enhances the extensibility of the model architecture. In this paper we will discuss the structure of the custom component and parameter generators and provide several examples where this feature can be used to easily create new and unique component definitions within the model.

9452-26, Session 5

Investigating the validity of the networked imaging sensor model in field of view search

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The Networked Imaging Sensor (NIS) model takes as input target acquisition probability as a function of time for individuals or individual imaging sensors and outputs target acquisition probability for a collection of imaging sensors and individuals. System target acquisition takes place the moment the first sensor or individual acquires the target. The derivation of the NIS model suggests it is applicable to multiple moving sensors and targets. The only assumption in the derivation of the NIS model is the independence of the events that give rise to the target acquisition probabilities. For investigating the validity of the NIS model we consider a collection of single images where neither the sensor nor target is moving. This paper investigates the ability of the NIS model to predict system target acquisition performance when multiple observers view first and second Gen field of view imagery that has either zero or one stationary target in a laboratory environment when observers have a maximum of 12 seconds to acquire the target when it is present. Comparison is made between modeled and measured target acquisition performance.

9452-27, Session 5

Model of Large-format EO-IR sensor for calculating the probability of detection and false alarm for fixed and moving targets

Andrew R. Korb, Korb Satellite Systems (United States)

A model was developed to calculate probabilities of detection and false alarm for moving and stationary targets observed in large-format EO and IR motion imagery. False positive detection probability and false positive rate per frame are calculated as a function of target-to-background contrast and target size. Results show that moving targets are more difficult to detect than stationary targets because for fixed targets the false detection rates diminish rapidly with successive frames whereas for moving targets the false detection rate remains constant or increases with successive frames. The model specifies how the desired performance of a detection system, measured by the false positive detection rate, can be achieved by image system designs with different combinations of SNR and spatial resolution, and this capability enables system design trades and cost optimization. For operational use, detection thresholds required to achieve a particular false detection rate can be calculated. Interestingly, for moderate size images the model converges to the Johnson Criteria. Johnson found that an imaging system is likely to detect targets when the target has 4 pixels area or more and an SNR >3.5. Under these conditions our model finds the false positive rate is much less than one per image frame, and the ratio of the probability of target detection to false alarm rate becomes much greater than one. The model was programmed into Matlab to generate simulated images frames for visualization.

9452-28, Session 5

Face acquisition camera design using the NV-IPM image generation tool

Kenneth A. Byrd, Joseph P. Reynolds, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

In this paper, we demonstrate the utility of the Night Vision Integrated Performance Model (NV-IPM) Image Generation Tool to create a database of face images with controlled degradations. Available face recognition algorithms can then be used to directly evaluate the camera design using these degraded images. By controlling camera effects such as blur, noise, and sampling, we can analyze algorithm performance and establish a more complete performance standard for face acquisition cameras. The ability to accurately simulate imagery and directly test with algorithms not only improves the system design process but greatly reduces cost.

9452-29, Session 5

Detection range estimation model for LWIR polarimetric camera

S?awomir Gogler, Military Univ. of Technology (Poland)

In infrared optical design one of key aspects considered in military applications is range at which target can be detected, recognized and identified. For many years Johnson criteria have been used to establish these ranges. This well-known approach bases on geometrical resolution factors (such as line pairs resolved by a system across a target) and simple energy-based factors, such as MRTD and atmospheric extinction. This approach has been widely used mostly due to simplicity of its application. In recent years however better, much more reliable and accurate methods of calculations have been developed. Since Johnson criteria have been found to be overly pessimistic these new approaches give a designer more freedom and can make a design cheaper while still meeting range requirements. Among these relatively new approaches (or "metrics") Targeting Task Performance method has gained much attention. In the article the TTP method is analyzed in context of polarimetric imaging. Since thermal contrast is not required for polarimetric signature to be detected, some modifications of the method need to be employed. Polarimetric contrast formulations are considered as well as traditional thermal contrast formulations with respect to their spatial domain content. For polarimetric signatures single pixel can be sufficient to detect a signature, hence approach based on energy relations is introduced and incorporated with simplified TTP method. Polarimetric signature will often depend also on object's material properties and its orientation with regard to a source which is also taken into consideration.

9452-30, Session 6

Scene projection technology enhancements for testing infrared imaging sensors in a simulated environment

Heard S. Lowry, Aerospace Testing Alliance (United States)

A variety of scene-projection technologies are being used at Arnold Engineering Development Complex (AEDC) Space Systems Test Facility (SSTF) to provide ground testing of space-based and airborne imaging sensor systems. These sensor systems require visible-to-long wave infrared (LWIR) imaging sensor calibration and characterization, as well as Hardware in the Loop (HWIL) real-time simulation with high-fidelity complex scene projection to evaluate and validate sensor mission performance. Successfully accomplishing this suite of sensor testing requires continual development, evaluation, and implementation of these technologies into the simulated test environment. This paper provides an overview of recent technology development efforts at the AEDC SSTF.

9452-31, Session 6

Development of an ultrahigh-temperature infrared scene projector at Santa Barbara Infrared Inc.

Gregory Franks, Joseph D. Laveigne, Tom Danielson, Santa Barbara Infrared, Inc. (United States); John M. Lannon Jr., Scott H. Goodwin, RTI International (United States); Kevin Sparkman, Santa Barbara Infrared, Inc. (United States)

The rapid development of very-large format infrared detector arrays has challenged the IR scene projector community to also develop larger-format infrared emitter arrays to support the testing needs of systems incorporating these detectors. As with most integrated circuits, fabrication yields for the read-in integrated circuit (RIIC) that drives the emitter pixel array are expected to drop dramatically with increasing size, making monolithic large format RIICs impractical and unaffordable. Additionally, many scene projector users require much higher simulated temperatures than current technology can generate in order to fully evaluate the performance of their systems and associated processing algorithms.

Under the Ultra High Temperature (UHT) development program, Santa Barbara Infrared Inc. (SBIR) is developing a new infrared scene projector architecture capable of producing both very large format (>1024x1024) resistive emitter arrays and improved emitter pixel technology capable of simulating very high apparent temperatures. During an earlier phase of the program, SBIR demonstrated materials with MWIR apparent temperatures in excess of 1000K. New emitter materials have subsequently been selected to produce pixels that achieve even higher apparent temperatures. Test results from pixels fabricated using the new material set will be presented and discussed. Also in development under the same UHT program is a 'scalable' RIIC that will be used to drive the high temperature pixels. This RIIC will utilize through-silicon vias and Quilt Packaging technologies to allow seamless tiling of multiple chips to fabricate very large arrays, and thus overcome the yield limitations common in large-scale integrated circuits. Current status of the RIIC development effort will be presented.

9452-32, Session 6

Test pixels for high-temperature infrared scene projection

Christopher J. Fredricksen, LRC Engineering, Inc. (United States); Seth Calhoun, Stephen Trewick, Aubrey Coffey, Edward Dein, Kevin R. Coffey, Robert E. Peale, Univ. of Central Florida (United States); Joseph D. LaVeigne, Gregory Franks, Tom Danielson, Santa Barbara Infrared, Inc. (United States); John M. Lannon Jr., Scott H. Goodwin, RTI International (United States)

IR scene projection enables realistic simulations of infrared scenes to support hardware-in-the-loop testing of missile seekers, FLIRs, and other infrared imaging systems. Challenges for reaching the desired higher maximum pixel temperatures for emitter arrays based on resistive elements include materials issues such as oxidation of resistive elements, diffusion of impurities into dielectrics with resulting shorts, and strains due to recrystallization. One of the obstacles in developing new materials is the cost associated with running a lot of test pixels through the entire emitter fabrication process. To allow investigation of novel high-temperature materials without the cost of full finished-array manufacturing runs, we have designed simplified pixels for testing and developed processes to fabricate them. Device dies consist of conducting ribbon patterns sandwiched between dielectric layers on Si wafers. The ribbons consist of a resistive heating element connected to probe pads by conducting traces. Processing involves a pad exposure etch, a pixel outline etch, and an undercut etch to thermally isolate the resistive portion of the pixel from the substrate. Test pixels were successfully fabricated by electron-beam lithography using a combination of wet and dry etching.

9452-33, Session 6

Resolution specification for infrared scene projectors used in hardware-in-the-loop testing

Joseph D. LaVeigne, Gregory Franks, Tom Danielson, Santa Barbara Infrared, Inc. (United States)

Infrared scene projectors (IRSPs) are a key part of performing dynamic testing of infrared (IR) imaging systems. Two important properties of an IRSP system are apparent temperature and thermal resolution. Infrared scene projector technology continues to progress, with several systems capable of producing high apparent temperatures currently available or under development. These systems use different pixel technologies including resistive arrays, DMDs, liquid crystals and LEDs. One common theme in the systems is the specification of the bit depth of the read-in integrated circuit (RIIC) or projector engine (such as a digital micro-mirror device or DMD), as opposed to specifying the desired thermal resolution as a function of radiance or apparent temperature. For infrared systems, producing an accurate simulation of a realistic scene or scenario may require simulating radiance values that range over multiple orders of magnitude. Combined with variable transfer functions between commanded input and radiance output, a single value, especially at the RIIC level, may not offer the best representation of desired customer radiance resolution. A system may meet the specified bit depth, but not meet the desired thermal resolution. Conversely, a system may have adequate thermal resolution, but fail the bit depth requirement. In this paper, we discuss some of the various factors that affect thermal resolution of a scene projector, and propose a variable radiance resolution scale to better define the reals needs of an IR scene projector system.

9452-34, Session 6

Spectral homogenization techniques for the hyperspectral image projector

Logan E. Hillberry, Colorado School of Mines (United States); Joseph P. Rice, National Institute of Standards and Technology (United States)

In an effort to improve technology for performance testing and calibration of multispectral and hyperspectral imagers, the National Institute of Standards and Technology (NIST) has been developing a Hyperspectral Image Projector (HIP) capable of projecting dynamic scenes than include distinct, programmable spectra in each of its 1024x768 spatial pixels. The HIP is comprised of a spectral engine, which is a light source capable generating the spectra in the scene, coupled to a spatial engine, capable of projecting the spectra into the correct locations of the scene. In the prototype HIP, the light exiting the Visible-Near-Infrared (VNIR) / Short-Wavelength Infrared (SWIR) spectral engine is spectrally dispersed and needs to be spectrally homogenized before it enters the spatial engine. In this paper we describe the results from a study of several different techniques for performing this spectral homogenization. These techniques include an integrating sphere, a liquid light guide, a randomized fiber bundle, and an engineered diffuser, in various combinations. The spectral uniformity of projected HIP scenes is measured and analyzed using the spectral angle mapper (SAM) algorithm over the VNIR spectral range. SAM provides a way to analyze the spectral uniformity independently from the radiometric uniformity. The goal of the homogenizer is a spectrally uniform and bright projected image. Using an integrating sphere provides the most spectrally uniform image, but at a great loss of light compared with the other methods. The randomized fiber bundle outperforms the liquid light guide. Using an engineered diffuser with the randomized fiber bundle increases the spectral uniformity by a factor of five, with a decrease in brightness by a factor of five, compared with the randomized fiber bundle alone. The combination of an engineered diffuser with a randomized fiber bundle provides comparable spectral uniformity to the integrating sphere while enabling 200 times greater brightness.

9452-35, Session 6

Advances in iterative non-uniformity correction techniques for infrared scene projection

Tom Danielson, Joseph D. LaVeigne, Gregory Franks, Marcus Prewarski, Brian Nehring, Santa Barbara Infrared, Inc. (United States)

Santa Barbara Infrared (SBIR) is constantly developing new methods for non-uniformity correction (NUC) of its Infrared Scene Projectors (IRSPs) as part of its comprehensive efforts to achieve the best possible projector performance. The most recent step forward is called Advanced Iterative NUC and it improves upon previous NUC approaches in several ways. The key to NUC performance is the most accurate possible input drive-to-radiance output mapping for each emitter pixel. This requires many highly-accurate radiance measurements of emitter output, as well as sophisticated manipulation of the resulting data set. Advanced Iterative NUC expands the available radiance data set to include all measurements made of emitter output at any point, and allows the user to efficiently manage that data and select any subset to use in the construction of a new NUC table that is generated from an improved fit of the emitter response curve. Not only does this improve the NUC by offering more statistics for interpolation than ever before, it also makes it simple to remove erroneous data from the set so that it does not propagate into the correction tables. Advanced Iterative NUC is implemented by SBIR's IRWindows4 automated test software as part its advanced turnkey IRSP measurement, calibration and NUC product called the Calibration Radiometry System (CRS). By employing Advanced Iterative NUC on the CRS, SBIR has produced the best uniformity results on resistive emitter arrays to date.

9452-36, Session 6

Computing the total atmospheric refraction for real-time optical imaging sensor simulation

Richard F. Olson Jr., U.S. Army Research, Development and Engineering Command (United States)

Fast and accurate computation of light path deviation due to atmospheric refraction is an important requirement for real-time simulation of optical imaging sensor systems. A large body of existing literature covers various methods for application of Snell's Law to the light path ray tracing problem. This paper provides a discussion of the adaptation to real time simulation of atmospheric refraction ray tracing techniques used in mid-1990's MODTRAN releases. The refraction ray trace algorithm and model atmospheres published in a MODTRAN 2/3 technical report by Kneizys (et. al.) have been coded in C-language for simulation use. To this published algorithm we have added extensions for variable path segment lengths, and for ascending, descending, transitioning and exoatmospheric "near Earth" ray paths. An important aspect of these extensions is that distance to the observed source may be specified from any relative viewing geometry. Another modification to the published ray trace algorithm implements two key "tuning" parameters for variable path segment length. These parameters govern the accuracy of the computed refraction offset angle. The MODTRAN-based refraction model is applicable to atmospheric propagation at wavelengths in the IR and visible bands of the electromagnetic spectrum. It has been used during the past two years by engineers at the U.S. Army Aviation and Missile Research, Development and Engineering Center (AMRDEC) in support of several advanced imaging sensor simulations.

9452-37, Session 6

Memory efficient atmospheric effects modeling for infrared scene generators

Çaglar Kavak, Seçkin Özsaraç, TÜBİTAK BİLGEM İLTAREN (Turkey)

The infrared (IR) energy radiated from any source passes through the atmosphere before reaching the sensor. As a result, the total signature captured by the IR sensor is significantly modified by the atmospheric effects. The dominant physical quantities that constitute the mentioned atmospheric effects are the atmospheric transmittance and the atmospheric path radiance. The incoming IR radiation is attenuated by the transmittance and path radiance is added on top of the attenuated radiation.

In IR scene simulations OpenGL is widely used for rendering purposes. In the literature there are studies, which model the atmospheric effects in an IR band using OpenGL's exponential fog model as suggested by Beer's law. In the standard pipeline of OpenGL, the related fog model needs single equivalent OpenGL variables for the transmittance and path radiance, which actually depend on both the distance between the source and the sensor and also on the wavelength of interest. However, in the conditions where the range dependency cannot be modeled as an exponential function, it is not accurate to replace the atmospheric quantities with a single parameter.

The introduction of OpenGL Shading Language (GLSL) has enabled the developers to use the GPU more flexible. In this paper, a novel method is proposed for the atmospheric effects modeling using the least squares estimation with polynomial fitting by programmable OpenGL shader programs built with GLSL. In this context, a radiative transfer model code is used to obtain the transmittance and path radiance data. Then, polynomials fits are computed for the range dependency of these variables. Hence, the atmospheric effects model data that will be uploaded in the GPU memory is significantly reduced. Moreover, the error because of fitting is negligible as long as narrow IR bands are used.

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9453-1, Session 1

Highly-transparent spinel windows by microwave sintering

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Transparent magnesium aluminate spinel (MgAl2O4) ceramic possesses excellent mechanical and optical properties enabling its potential use in many applications, especially those in harsh environments. We have previously demonstrated fabrication of transparent spinel ceramic with very low absorption loss (6ppm/cm) at 1 ?m using the hot pressing method (1). However, microwave sintering offers several potential advantages over conventional densification methods such as uniform heating, shorter sintering time, finer microstructure of the ceramics, and scalability to large sizes. Previous attempts to microwave sinter spinel powder resulted in only opaque or translucent ceramics (2). In this paper, we report the fabrication of highly transparent spinel ceramics using microwave sintering and highlight the optical, spectral, morphological and mechanical properties.

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9453-2, Session 1

Low-loss spinel windows for high-energy lasers

Woohong R. Kim, Guillermo Villalobos, Colin Baker, U.S. Naval Research Lab. (United States); Michael Hunt, Univ. Research Foundation (United States); Bryan Sadowski, Ishwar Aggarwal, Sotera Defense Solutions, Inc. (United States); Jasbinder S. Sanghera, Shyam S. Bayya, U.S. Naval Research Lab. (United States); Juan L. Sepulveda, Raouf O. Loutfy, Tim Lowe, Materials and Electrochemical Research Corp. (United States)

Ideal exit aperture windows for high-energy laser (HEL) should possess low absorption and scattering losses and be environmentally rugged and strong in order to protect the gain medium without compromising the light propagating through the window. A trace amount of chemical and physical impurities present in the windows will result in an adverse effect where a local heating caused by the impurities changing its refractive index and these changes, in turn, result in beam distortion and loss of output power, which has a severe impact on system performance. The conventional window materials such as fused silica and oxyfluoride (OFG) glasses do not satisfy HEL systems requirement to operate in harsh environmental conditions. Transparent magnesium aluminate spinel (MgAl2O4) ceramic, due to its excellent mechanical properties and wide IR transmission, has been considered as an ideal rugged window material for HEL systems. Transparent spinel ceramics windows fabricated using commercial powders often show high absorption and scattering mainly due to the presence of chemical and morphological impurities. Here, we report convenient and economical powder purification methods to significantly lower the absorption loss from transparent spinel ceramic. A jet mill method is also introduced to produce homogenous ceramic powders suitable to fabricate highly transparent and low scattering ceramics for high power laser application.

9453-3, Session 1

Transparent ceramics for demanding applications

Mark V. Parish, Marina R. Pascucci, John Gannon, Brenda Puputti, CeraNova Corp. (United States)

CeraNova's transparent ceramics have been developed for use in a number of applications, including those involving infrared transmission, RF transmission, lasers and scintillators. Transparent ceramic materials developed include alumina, spinel, yttria, YAG, and composites. The properties of CeraNova's high strength transparent alumina and magnesium aluminate spinel will be presented. Optical components made from CeraNova transparent ceramics will also be discussed.

CeraNova's transparent polycrystalline alumina (CeraLumina™) exhibits high transmittance in the mid-wave infrared (MWIR) and useful bands of transmission in the RF. The unique microstructure also leads to high hardness, high strength, and high thermal shock resistance. Polycrystalline alumina is a viable material where sapphire would be applicable without the constraint of size or shape; e.g., aerodynamic dome shapes. Transparent CeraLumina hemispheric and ogive dome blanks are routinely produced and optical fabrication examples these shapes will be presented. CeraNova's spinel has high transmittance in the visible and MWIR, and enhanced mechanical properties including equibiaxial flexure strength. Results of optical and mechanical testing for both materials will be presented.

9453-4, Session 1

20-inch diameter CHES® Sapphire Boules

Chandra P. Khattak, Joshua Filgate, Saurabh Ullal, Raj Shetty, C. Richard Schwerdtfeger, ARC Energy (United States)

This paper discusses the development of a new crystal growth system, Controlled Heat Extraction System (CHES®), which has produced high quality sapphire to meet the demands of the industry and is presently setting up to grow world's largest sapphire boules, 500mm diameter, 300kg. Correlation of technology development with different markets and timing will be discussed.

In 2007 it was recognized that for sapphire a transition from an exotic material to an industrial product could only be made with a new paradigm shift towards industrialization of sapphire production. The first market was Solid State Lighting (SSL) for which c-axis grown 150mm diameter CHES sapphire was produced. This was contrary to common belief that c-axis sapphire could not be grown in large sizes. This orientation advantage resulted in over 75% material utilization compared to less than 35% for conventional approaches. An important result of c-axis growth is that large diameter windows and domes are now available for zero birefringence optics.

In order to reduce costs further larger sapphire boule growth is being pursued. A CHES furnace capable of growing 500mm diameter, 300kg boules has been installed. Initial results with 380mm diameter, 190kg boule growth are very encouraging. Growth of 500mm diameter boules is being investigated. With CHES approach a-, r- or c-axis boules can be grown without changes to hardware. This will allow production of very large monolithic windows which has not been possible so far.

Details of the CHES process, approaches to reduce costs and characterization results will be discussed.

9453-5, Session 1

Large conformal ALON® windows

Santosh K. Jha, Lee M. Goldman, Robyn Foti, Suri A. Sastri, Sreeram Balasubramanian, Mark Smith, Surmet Corp. (United States)

Aluminum Oxynitride (ALON® Optical Ceramic) combines broadband transparency with excellent mechanical properties. ALON's cubic structure means that it is transparent in its polycrystalline form, allowing it to be manufactured via conventional powder processing techniques. Surmet controls every aspect of the manufacturing process, beginning with synthesis of ALON® powder, continuing through forming/heat treatment of blanks, ending with optical fabrication of ALON® windows. Surmet has made significant progress is production capability in recent years. Additional scale up of Surmet's manufacturing capability, for complex geometries, larger sizes and higher quantities, is currently underway.

The requirements for modern aircraft are driving the need for conformal windows for future sensor systems. However, limitations on optical systems and the ability to produce windows in complex geometries currently limit the geometry of existing windows and window assemblies to faceted assemblies of flat windows. Surmet's ability to produce large curved ALON® Blanks is an important step in the development of conformal windows for future aircraft applications.

9453-6, Session 1

Scatter properties of polycrystalline YAG and Nd:YAG in the visible and near-infrared

R. M. Springer, Michael E. Thomas, A. M. Brown, Johns Hopkins Univ. (United States)

No Abstract Available

9453-7, Session 2

Roadmap for transparent advanced ceramic sensor windows

Douglas W. Freitag, USACA (United States)

USACA has developed an industry lead roadmap for transparent advanced ceramic sensor windows. The roadmap was developed in response to market trends extreme environments, expanded battlefield networks, increasing sensor window size, increasing sensor resolution, desired for more complex shapes, multi-band windows, and increased multi-functionality. Input was provided from subject matter experts throughout the value chain and the federal government. Data was collected on the challenges and needs that remain for application of sensor windows, the investment required, and the timeline. Sensor windows were considered operating in the visible, IR and RF. Examples of challenges identified include cost, size, shape, mounting, coatings, multi-band, performance, testing, industrial base sustainment and transition. Results of the roadmap will be discussed along with plans for broader vetting and implementation.

9453-8, Session 2

A history of semi-active laser dome and window materials *(Invited Paper)*

Roger M. Sullivan, Office of Naval Research (United States)

Semi-Active Laser (SAL) guidance systems were developed starting in the mid-1960's and today form an important class of precision guided weapons. The laser wavelengths generally fall in the short wave infrared region of the spectrum. Relative to passive, image based, infrared seekers the optical demands placed on the domes or windows of SAL seekers is very modest, allowing the use of low cost, easily manufactured materials, such as polycarbonate. This paper will examine the transition of SAL window and dome science and technology from the laboratory to battlefield, with special emphasis on the story of polycarbonate domes.

9453-9, Session 2

Weibull probability of failure analysis of windows and domes: a tutorial *(Invited Paper)*

Lee R. Cambrea, Daniel C. Harris, Naval Air Warfare Ctr. Weapons Div. (United States)

This tutorial paper describes the application of Weibull statistics from mechanical strength testing to predict the static probability of survival of a polished optical window or dome under stress. The process uses the built-in Solver routine of an Excel spreadsheet to derive the Weibull modulus and characteristic strength from mechanical test data without distortion by logarithmic transformation. From the modulus and characteristic strength, the probability of survival of each element of surface area of a window or dome under tensile stress can be calculated. The overall probability of survival is the product of probabilities of survival of each tensile surface element.

9453-10, Session 3

Updates in high-performance window fabrication

Teddy J. Lambropoulos, Zygo Corporation (United States)

As the intelligence, surveillance and reconnaissance, and high energy laser systems have evolved and progressed, so has the demand for advancing the capabilities of high-performance windows and other optical components. These increasing market demands include tighter optical performance specifications, challenging materials to manufacture, increasing sizes, and new geometries. To meet these various requirements, Zygo Corporation continues to improve its optical fabrication technology and metrology systems. Zygo has developed efficient manufacturing processes for a wide range of optical materials ranging from, but not limited to, optical glass (such as fused silica and ULE), polycrystalline materials (e.g. ZnS and Multi-Spectral-ZnS), and hard ceramics (such as AlON, spinel, sapphire, and silicon carbide). Furthermore, a so called "Super-Finishing" surface smoothing process has also been developed that is capable of achieving sub 0.1nm rms surface roughness over a spatial band ranging from 10 nm to 1 mm for several key materials. Zygo is capable of manufacturing optical components with a variety of geometries including high aspect ratio windows, meter class optics, on or off-axis aspheres and even true freeform surfaces. This paper will discuss and provide several examples regarding the advancements Zygo has made relating to material processing, window geometries, and optical specifications.

9453-11, Session 3

Development of manufacturing technologies for hard optical ceramic materials

Edward Fess, Scott DeFisher, Mike Cahill, Frank L. Wolfs, OptiPro Systems (United States)

Hard ceramic optical materials such as sapphire, ALON, Spinel, or PCA can present a significant challenge in manufacturing precision optical components due to their tough mechanical properties. These are also the same mechanical properties that make them desirable materials when used in harsh environments. Premature tool wear or tool loading during the grinding process is a common result of these tough mechanical properties. Another challenge is the requirement to create geometries that conform to the platforms they reside in, but still achieve optical window tolerances for wavefront. These shapes can be complex and require new technologies to control sub aperture finishing techniques in a deterministic fashion. In this paper we will present three technologies developed at OptiPro Systems to address the challenges associated with these materials and complex geometries. The technologies presented will show how Ultrasonic grinding can reduce grinding load by up to 50%, UltraForm Finishing (UFF) and UltraSmooth Finishing (USF) technologies can accurately figure and finish these shapes, and how all of them can be controlled deterministically, with utilizing metrology feedback, by a new Computer Aided Manufacturing (CAM) software package developed by OptiPro called ProSurf.

9453-12, Session 3

Form, figure, and thickness measurement of freeform and conformal optics with non-contact sensors

Scott DeFisher, Edward Fess, Greg Matthews, OptiPro Systems (United States)

Advancements in optical manufacturing technology allow optical designers to implement freeform and conformal shapes in their systems. Metrology of the shapes has traditionally been difficult, especially at the sub-micron level. Contact measuring systems typically lack the accuracy required for optical qualification and can damage the surface. Interferometric systems are unable to handle high spherical departures and may require complicated lateral calibration to generate feedback for deterministic grinding and polishing. OptiPro has developed UltraSurf, a non-contact coordinate measuring machine to determine the form, figure, and thickness of freeform and conformal optics. We integrated several non-contact sensors that acquire surface information through different optical principles. Each probe has strength and weaknesses relative to an optic's material properties, surface finish, and figure error. The measuring probe is scanned over the optical surface while maintaining perpendicularity and a constant focal offset. Measurements of freeform and conformal shapes will be presented. The scanning method of UltraSurf and the non-contact probes will also be shown. The form, figure, and thickness data will highlight the capabilities of UltraSurf to measure freeform surfaces. Comparisons between accuracy and measureable surface departure will be made with current metrology systems such as coordinate measuring machines, interferometers, and profilometers. Additionally, methods for defining a freeform or conformal surface for metrology analysis and manufacturing will be discussed.

9453-13, Session 3

Freeform optical manufacturing and testing processes for IR conformal window and domes

Kate Medicus, Jessica D. Nelson, Timothy Lynch, Matt Brunelle, Matthew R. Brophy, Optimax Systems, Inc. (United States)

Freeform shapes, defined as surfaces without symmetry, are becoming more commonplace in the optical design industry. These freeforms require special manufacturing and testing considerations and do not easily lend themselves to utilizing traditional optical specifications and tolerances. This talk will include an overview of current freeform manufacturing and testing processes for producing freeform surfaces. Discussion topics will also be presented for future collaboration between optical designers and fabricators regarding freeform specifications and tolerancing methods. Successes, lessons learned and future work will be highlighted through specific examples of polycystalline infrared conformal windows, domes and corrector elements.

9453-14, Session 3

Optical metrology of conformal optics

Mikhail A. Gutin, Olga Gutin, Xu-Ming Wang, Dennis Ehlinger, Applied Science Innovations, Inc. (United States)

Conformal windows and domes improve aerodynamic quality of missiles and aircraft but introduce significant optical aberrations. These aberrations can be compensated by corrective optics, provided both window and corrective optics are fabricated to high tolerances. Highly accurate measurement of conformal optics is required for success of the fabrication process. A broader range of applications for metrology of aggressively aspheric optics is in fabrication of aspheric and freeform optics such as used in head-mounted and head-up displays. This paper presents an overview of existing and emerging metrology techniques for measurement of highly aspheric wavefronts and surfaces, and describes the development of the Interferometric Tomography – a new tool for metrology of conformal aspheric optics. The metrology system is designed to measure wavefront aberrations as well as the optical figure of both surfaces.

9453-15, Session 4

Additive manufacturing of optical materials

Junjie Luo, Luke Gilbert, Douglas Bristow, Robert Landers, Edward C. Kinzel, Missouri Univ. of Science and Technology (United States)

Additive manufacturing, or 3D printing, has been used for printing plastics, metals, and some ceramics. However, comparatively little work has been performed on printing glass and other optical components aside from polymers. Ongoing work is presented on depositing transparent glass components. This consists of a comparative study between three additive processes, powder bed, blown-powder and wire fed. In these processes a CO_2 laser is used to locally melt the glass and build 3D shapes. The 10.6 um laser energy is well absorbed by the glass. The build platform is scanned by moving a heated build platform under a stationary laser beam. In all the processes, material is consolidated by melting process solidifies out of the melt pool as the part translates relative to the laser beam.

The key parameters for each process are identified, notably the scan speed, laser power, and feed-rates. These are mapped in terms of their effects on the morphology. The relationship between these parameters is studied experimentally and corroborated with numerical simulations (ANSYS Fluent) of the melt pool temperature.

We use the optimized parameters to build walls of glass. These are polished and the transmission measured. Generally the wire-fed process outperforms the powder-based processes. This is due to scattering off entrapped bubbles that limits the transmission through powder built parts while wire-fed parts approach the transparency of furnace cast pieces.

Because the additive manufacturing process allows the material composition of the work piece to be adjusted on a 3D volumetric basis it

will be useful for making gradient index optics. In addition it is useful for printing integrated photonics and depositing hermetic seals.

9453-16, Session 4

ALON® GRIN optics for Visible-MWIR applications

Nagendra Nag, Surmet Corp. (United States)

Surmet has continuously strived to introduce novel and trailblazing advanced optical ceramics products for current and future defense and commercial systems. With conventional powder processing techniques, Surmet has progressed its ALON® technology to manufacture large and optically transparent armor plates and domes. In addition to transparency at the required wavelengths, many functionalities including EMI shielding, internal heaters, internal antennas and cooling channels etc. have been demonstrated in dimensions that are of interest to many applications.

Surmet, working closely with the University of Rochester, has developed gradient index (GRIN) optics in ALON® for use in the visible through the MWIR bands. Surmet has demonstrated the ability to tailor the refractive index of the ALON® material by either varying its composition or through the addition of dopants. With the development of several enabling process technologies, smooth axial and radial gradient profiles with ~0.055 change in refractive index, over depths of 1-8 mm (axial) and over 20 mm radius (radial) have been achieved. Initial design studies with ALON GRIN have shown such elements to provide uniquely advantageous color correction characteristics over multispectral wavebands. Radial gradients in particular, with their optical power contribution, are expected to provide additional degrees of freedom for color correction in broadband imaging systems.

Surmet is continuing to work in maturing the technology of ALON® GRIN elements along with metrology and GRIN optical design development. Surmet is committed to developing manufacturing capability for ALON® GRIN elements and inserting it into novel imaging solutions for military and other commercial systems.

9453-17, Session 4

Cost-effective and high-strength ZnS IR windows for LWIR applications

Duraiswamy Ravichandran, Texas Biochemicals, Inc. (United States)

The goal of this project is to fabricate cost-effective and high strength Zinc Sulfide (ZnS) IR windows using ceramic powder processing to avoid an expensive state-of-the-art chemical vapor deposition (CVD) method.

Erosion-resistant ZnS could be fabricated through various novel sintering routes and addition of IR Transparent additives to ZnS to enhance its strength. We have attempted to add additives to produce large scale monodispersed ZnS nanoparticles (100 nm) by a novel route. The powder X-ray diffraction patterns of ZnS shows the presence of broad reflections corresponding to the (1 1 1), (2 2 0), and (3 1 1) planes of the cubic crystalline ZnS material. This novel route produced ultrahigh purity, homogeneous, well dispersed, and monodispersed ZnS nanoparticles. The correlation of processing variables with respect to additives, strength, morphology, purity, IR transmittance, X-ray diffraction and TEM analysis will be presented.

9453-18, Session 4

Scintillation and luminescence in transparent colorless single and polycrystalline bulk ceramic ZnS

John S. McCloy, Washington State Univ. (United States); Mary Bliss, Brian W. Miller, Zheming Wang, Sean C. Stave, Pacific Northwest National Lab. (United States)

ZnS:Ag is a well-known, extremely bright scintillator used in powder form for ?-particle detection and, mixed with powdered LiF, for thermal neutron detection. Recently, we discovered some colorless and transparent commercial bulk single-crystal and polycrystalline (chemical vapor-deposited) ZnS forms that scintillate in response to ?-particles. The scintillation light transmits through the sample thickness (millimeters), challenging the commonly held assumption that ZnS is opaque to its own scintillation light. Individual ?-particle events were imaged in space and time using a charged-particle camera originally developed for medical imaging applications. Photoluminescence (PL) and PL excitation show that scintillating bulk ZnS likely depends on different electronic defects than commercial ZnS powder scintillators. These defects, associated with copper and oxygen, are discussed in relation to PL results and extensive literature assessment. Commercial transparent ZnS is routinely produced by chemical vapor deposition to sizes larger than square meters, enabling potentially novel radiation detection applications requiring large, thick apertures.

9453-19, Session 4

Advances in multispectral diamond-like carbon coatings

Jason Keck, Chris Karp, Reynard Corp. (United States)

Whether in military windows, night vision devices, or supermarket scanners, harsh environments are often the scene of light needing to pass through a robust material. Improving durability has traditionally incurred an inevitable sacrifice in transmission, particularly in the visible. We discuss a Diamond-Like Carbon (DLC) coating that provides the durability of DLC, but does so with greater transmission in the IR than with traditional coatings of this type, and with significantly more transmission across the visible. The visible to far infrared spectral range of this material opens up DLC use to visible and multi-spectral applications: laser designators, field barcode scanning, night (and day) vision devices. This extended and improved transmission profile is achieved by introducing an index and stress matching intermediate material deposition between the substrate and the DLC layer. Instead of a coating of 100 percent DLC, the intermediate layer is capped by a tunable thickness of DLC that best matches the requirements of the desired application.

To bring this design to life, we developed a deposition system that provides for the simultaneous use of the several different technologies required to manufacture this material. The reduced thickness of the DLC layer enables higher transmission, but this is achieved without sacrificing durability, making it suitable for applications in which the coating has to withstand airborne particulate impacts, corrosive fluids, environmental extremes, and abrasive physical handling.

9453-20, Session 4

Simple optimization method for EMI mesh pattern design

Mehmet Erhan Alpman, Tolga Senger, ASELSAN Inc. (Turkey)

Metallic mesh coatings are used on visible and infrared windows and domes widely to provide shielding from EMI (electromagnetic interference). Different EMI mesh geometries are compared with each other regarding various performance parameters. But to decide best fitting EMI mesh geometry to particular optic system is little bit complicated issue. Therefore we try to find simple methodology to decide best EMI mesh geometry design that fits our particular high performance ISR(Intelligence Surveillance Reconnaissance) systems."

9453-21, Session 4

Stress Measurement of EFG Sapphire Using Cr3+ Piezospectroscopy

Drew T. Haven, Herbert E Bates, John W Locher, Steven A. Zanella, Saint-Gobain Crystals (United States)

Sapphire's excellent hardness, strength, and UV-IR transmittance make it an excellent candidate for IR window and transparent armor applications. At Saint-Gobain Crystals, Edge-defined Film-fed Growth (EFG) sapphire crystals are currently being grown at production quantities in sizes up to 305 mm wide by 560 mm long by 11 mm thick. However, the demand for even larger sapphire panels continues to grow. In order to aid in the development of larger pieces, a nondestructive analysis has been developed to measure planar stress in sapphire panels, utilizing a Cr3+:Al2O3 piezospectroscopy technique first developed to measure stress in diamond anvil cells.

The measurement works by utilizing trace amounts of naturally occurring Cr3+ impurities present in sapphire. Upon optical excitation, the Cr3+ will luminesce and produce a sharp emission doublet centered at 694 nm with the two peaks dubbed R1 and R2. This emission results from a 2E ? 4A2 transition of Cr3+ in sapphire and its exact emission energy is dependent on the distance between Cr3+ and O2- ions in the sapphire crystal, which varies with stress. As a result, measurement of the Cr3+ emission, and the corresponding shift of the Cr3+ doublet wavelength, can be used as a nondestructive means of measuring stress. By recording several data points over an array, it is possible to construct a stress map of large sapphire sheets.

9453-22, Session 5

Electronic-band structures and optical properties of transition metal-doped zinc oxide

Esakkimuthuraju Murugan, Mahesh Rajendran, Badrinath Vadakkapattu Canthadai, Venugopal Reddy Paduru, Sreekanth Tirumala, Vidya Jyothi Institute of Technology (India)

Wide band gap Oxide based diluted magnetic semiconductors (ODMS) exhibit unique magnetic, magneto-optical and magneto-electrical effects and can be exploited as a spintronic devices. Theoretical studies of transition metal (TM) doped zinc oxide which belongs to these class of materials has been attracting significant research interest in the recent years. In this paper, the electronic structures, and band gap energies of ZnO doped with different transition metals have been analyzed by ab initio calculations based on the density functional theory using quantum espresso PWscf code. For the band gap calculations, we have used both local density approximation (LDA) and generalized gradient approximation (GGA). The magnetic and optical properties of the materials have been studied using the above method. For all the theoretical calculations, the model structures of transition metal-doped ZnO were constructed by using the 24-atom 2 ? 1 ? 1 supercell with one Ti atom replaced by a transition metal atom. The results are useful in understanding the band gap variations with doping and other related properties in oxide based diluted magnetic semiconductors such as ZnO.

9453-23, Session 5

Role of impactor properties on computational simulation of sand impact damage in transparent ceramic windows

Robert Schultz, The Univ. of Arizona (United States); Ibrahim Guven, Virginia Commonwealth Univ. (United States); Brian J. Zelinski, Raytheon Missile Systems (United States)

No Abstract Available

9453-24, Session 5

Computational modeling of sand impact damage in coated, transparent ceramic windows

Shanna Tune, Robert Schultz, The Univ. of Arizona (United States); Ibrahim Guven, Virginia Commonwealth Univ. (United States); Brian J. Zelinski, Raytheon Missile Systems (United States)

No Abstract Available

9453-25, Session 5

New ZnS interatomic potential for molecular dynamics simulations

Erin K. Boland, Raytheon Missile Systems (United States); Krishna Muralidharan, The Univ. of Arizona (United States); Brian J. Zelinski, Raytheon Missile Systems (United States); Stefan Bringuier, The Univ. of Arizona (United States)

No Abstract Available

9453-26, Session 5

Stress analysis of optical coatings for improved durability and performance of high-end optical components

Shay Joseph, Anna Gleizer, Doron Yadlovker, Arit E. Shinman-Avraham, Rafael Advanced Defense Systems Ltd. (Israel)

One of the main challenging requirements from modern optical systems is the ability to function in severe environmental conditions for prolonged periods without suffering from performance degradation. Essential parts of such electo-optical systems are windows, domes and other optical elements most often coated with an efficient, multispectral and highly durable anti-reflection coatings. The complexity further increases when these coatings are applied on curved surfaces, such as hemispherical domes that are used in order to allow a wider field of view. The durability of the coated optical component is dependent upon many different parameters such as deposition method and process parameters and the adhesion between layers and substrate. However, one very important parameter, which can have a significant impact on the durability and optical performance, is the stress state of the applied anti-reflection layers. This subject is mostly left untreated mainly due to the difficulty of characterization and modeling techniques and lack of thin film mechanical constants which sometimes significantly differ from the bulk constants of the same material. The stress state of the optical part is mainly determined by the mechanical properties of the coating materials and substrate, geometrical shape of the part and the thickness of the layers. In this work, both analytical and experimental approaches were used for characterization of stress distribution in thin films on curved surfaces. In the case of the electron beam gun evaporation method, which is most commonly used for anti-reflection coatings, the change in mechanical properties and thickness over the substrate curvature must be considered in order to achieve a true stress distribution. The mechanical properties and thickness distributions of the film were evaluated

experimentally using test samples positioned in a dome shaped mechanical fixture. The film thickness was measured using Atomic Force Microscope and the mechanical properties such as Young's Modulus and Poisson ratio were studied by using the nano-indentation technique. Finite element simulations were used in order to estimate the stress distribution in a multilayer anti reflection coating on a hemispherical dome. First, the finite element model was successfully compared to the analytical Timoshenko solution of stress state in a single layer thin film. Next, the finite element model was compared to the numerical solution of a multilayer thin film stress distribution on flat surfaces. Finally, finite element analysis was performed on single and multilayer optical coatings on a hemispherical dome with varying thickness and mechanical properties of each film. In this study, the stress state of a multi-layer anti-reflection coating on a hemispherical optical dome was defined. This would allow the engineer to design a part with the desired stress state which alongside the optical design, is expected to bring about a significant improvement in the durability and optical performance.

9453-28, Session 5

Laser-induced damage threshold prediction of dielectric-enhanced multiband mirrors at 1064 nm

Jue Wang, Corning Advanced Optics (United States)

Surface mitigation plays an important role on surface quality of diamond turned aluminum alloy Al-6061 for optical applications, especially for achieving high laser damage resistance and prolonged environmental durability. A 10X increase of laser-induced damage threshold was realized on the aluminum alloy via physical vapor deposited aluminum (PVD-Al). HfO2 and SiO2 multilayers were used to further enhance spectral reflectance and laser damage resistance of the PVD-Al modified aluminum alloy. Broadband spectral reflectance specification was realized, ranging from the visible to the MWIR. A laser-induced damage threshold of 5.0 J/cm2 was determined at 1064 nm, which doubles the value when compared to that of the PVD-modified aluminum alloy. Damage morphology analysis indicated laser-induced damage penetrates down to the aluminum substrate with a damage size close to the test laser beam footprint. Potential damage mechanisms, as well as LIDT as a function of overall HfO2 and SiO2 multilayer enhancement, were discussed. The results suggest that a combination of proper coating design and deposition process enables one to to achieve desired spectral performance as well as extremely high laser-induced damage threshold up to ~ 100 J/cm2.

9453-29, Session 5

Angle-resolved scatter of HfO2/SiO2 multilayer high-reflective coating at 1064 nm

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HfO2/SiO2 has been recognized as the best coating material combination for laser durable coatings in the near IR spectral region. Light scattering properties of the HfO2/SiO2 multilayer high reflective coatings to be considered for high quality IR imaging applications. For the investigations presented in this paper, angular resolved scattering (ARS) measurement was performed at a wavelength of 1064 nm at normal incidence on HfO2/SiO2 multilayer high reflector deposited on a silicon substrate via a modified plasma ion assisted deposition. A total backscatter of 3.9x10-4 was obtained by integrating the ARS data over the reflective hemisphere within a scatter angles ranging from 2o to 85o. A good agreement was found between the total backscatter derived from the ARS and the calculated scatter loss based on surface and interface roughness assuming fully correlated interfaces. The surface roughness was determined by atomic force microscopy. The result suggests that the ARS measurement can advantageously be used for roughness analysis. Interference fringes presented in the ARS at angles greater than 30o were correlated with a rather large bandwidth of the coating. Integrated near angle scattering was determined by separating the sample scatter from the instrument signature.

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9454-1, Session 1

Forecasting the soil-dependent performance of ground-penetrating radar by means of a conventional field-moisture sensor

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With emerging use of ground-penetrating radar (GPR) for IED and landmine detection, the demand of a forecasting method came up that enables to analyse the GPR performance with respect to the soil. The reason for this is that on-site GPR measurements with visual or acoustic real-time analysis unfortunately cannot provide the information whether or not the GPR method is suitable for the soil at all. However, the knowledge of the limitations of a technique is of vital importance in the field.

Especially for high-frequency GPR applications, various electromagnetic (EM) loss mechanisms in the soil can play a crucial role. Apart from scattering effects caused by soil heterogeneity, intrinsic attenuation controls the wave propagation in the subsurface. The intrinsic attenuation, which is due to EM energy losses, depends on the frequency of the EM field and is controlled by the effective electrical and dielectric soil properties.

We investigated the EM properties of various soils from Germany and Afghanistan using different laboratory and field methods. We found that intrinsic attenuation cannot be described by direct current electrical conductivity alone since dielectric relaxation mechanisms prevail at high frequencies. We propose a conventional soil-moisture field sensor based on time-domain reflectometry (TDR) as an alternative to the time-consuming laboratory measurements. The TDR probe was calibrated by means of the coaxial transmission-line technique and measures the intrinsic attenuation as well as the relative dielectric constant. Comparisons between the GPR performance forecast carried out by on-site TDR measurements and the experimental GPR performance shows a promising correlation.

9454-2, Session 1

Stand-off explosive detection utilizing low-power stimulated emission nuclear quadrupole resonance detection and sub-wavelength focusing wideband super lens

William Mouyos, John Apostolos, Judy Feng, Walter Chase, AMI Research and Development (United States)

The need for advanced techniques to detect improvised explosive devices (IED) at stand-off distances greater than ten (10) meters has driven AMI Research and Development (AMI) to develop a solution to detect and identify the threat utilizing a forward looking Synthetic Aperture Radar (SAR) combined with our CW radar technology Nuclear Quadrupole Resonance (NQR) detection system. The novel features include a near-field sub-wavelength focusing antenna, a wide band 300 KHz to 300 MHz rapidly scanning CW radar facilitated by a high Q antenna/tuner, and an advanced processor utilizing Rabi transitions where the nucleus oscillates between states under the time dependent incident electromagnetic field and alternately absorbs energy from the incident field while emitting coherent energy via stimulated emission. AMI's Subwavelength Focusing Wideband Super Lens uses a Near-Field SAR, making detection possible at distances greater than ten (10) meters. This super lens is capable of operating on the near field and focusing electromagnetic waves to resolutions beyond the diffraction limit. When applied to the case of a vehicle approaching an explosive hazard the methodologies of synthetic aperture radar is fused with the array based super resolution and the NQR data processing detecting the explosive hazard.

9454-3, Session 1

Minimally disruptive schedule repair for MCM Missions

Kalyan M. Gupta, Matthew Molineaux, Bryan L. Auslander, Philip G. Moore, Knexus Research (United States)

Mine countermeasures (MCM) missions entail planning and operations in very dynamic and uncertain operating environments, which pose considerable risk to personnel and equipment. Frequent schedule repair is needed that considers the latest operating conditions to keep mission performance on target. However, this is very challenging when performed manually because of the large number of variables, resources, and operating constraints that must be considered. We present a novel approach to perform this automatically and incrementally through the use of case-based rescheduling. This technique permits the storage and reuse of repair strategies that are proven successful in similar situations. We evaluate the performance impact of automated schedule repair in terms of time taken to correct a schedule; our results will show substantial savings in terms of operator effort compared to average time required to conduct these changes manually.

9454-4, Session 1

Fusion of iECO image descriptors for buried explosive hazard detection in forward-looking infrared imagery

Stanton R. Price, Derek T. Anderson, Mississippi State Univ. (United States); James M. Keller, Univ. of Missouri-Columbia (United States)

Data fusion is a powerful theory that often leads to significant performance benefit and/or improved robustness of a given solution. In this article, we explore how fusion can be used to advance our previously established iECO image descriptor framework. The goal of iECO is to learn not one, but a diverse set of individuals (variable length chromosome in a genetic algorithm). Each iECO individual encodes a unique composition of different low-level image transformations in the context of a high-level image descriptor. Two fusion strategies are investigated herein; ensemble theory and non-linear classifier confidence aggregation. The prior is particularly interesting as the problem at hand requires the fusion of multiple inputs, each of which reside in a different feature space. The latter fusion strategy is investigated in the context of the Choquet integral, a powerful non-linear aggregation operator that is parameterized by the fuzzy measure (aka capacity), which can be specified or learned from data. The proposed theory is presented in the context of buried explosive hazard detection in forward looking imagery. Experiments are reported using 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.

9454-5, Session 2

Detection of concealed targets using spintronic microwave sensor

Lei Fu, Yongsheng Gui, Can-Ming Hu, Univ. of Manitoba (Canada); Yang Xiao, Mounir Jaidann, Hong Guo, McGill Univ. (Canada); Hakima Abou-Rachid, Defence Research and Development Canada, Valcartier (Canada)

Microwave radiation can propagation through large distances in space and has modest attenuation when passing through physical barriers such as clothing, plastics, soil, sands, and rocks. Thus microwaves can interact with subsurface structures in addition to structures on the surface of the material. This subsurface imaging is attractive for non-destructively detecting embedded defects and/or concealed threats. Recent advances in spintronics has explored the possibility to measure the scattered microwave using a single spintronic device, and demonstrated that spintronic technique allows a real-time measurement of both the amplitude and phase of microwaves with a high sensitivity in a large dynamic range using a magnetic tunnel junction (MTJ). The operation principle enables the measurement performed by the less-expensive instruments (lock-in amplifier) working at low frequency range. The experiment-friendly low-frequency signal also makes sensor-based systems field-durable. The use of spintronic devices, which are able to operate at the same frequency range as current antenna but are a fraction of the size, allows the built system to be both compact and portable. In this paper, a microwave holographic imaging system has been established, where the microwave scattering data measured by an MTJ is reconstructed to generate a readable image based on the holographic principle. The system has demonstrated the feasibility to detect not only the existence of the concealed objects but also their shapes, allowing the concealed threat being distinguished along with other hidden objects. Finally, a theoretical model is constructed to simulate spin polarized transport in MTJ under microwave irradiation and to help interpret the measured data. First principles calculations of dielectric response in the microwave range for a number of energetic materials are also reported.

9454-6, Session 2

Differential excitation spectroscopy for detection of common explosives: ammonium nitrate and urea nitrate

Boyd V. Hunter, Jason M. Cox, Kestrel Corp. (United States); Michael A. Miller, Southwest Research Institute (United States); Richard V. Hunter, Paul Harrison, Levi Van Bastian, William P. Walters, Kestrel Corp. (United States)

Differential Excitation Spectroscopy (DES) is a new pump-probe detection technique which characterizes molecules based on a multi-dimensional parameterization of the rovibrational excited state structure, pump and probe interrogation frequencies, as well as the lifetimes of the excited states. Under appropriate conditions, significant modulation of the ground state can result. DES results provide a unique, simple mechanism to validate and understand various molecules in support of relevant science. In addition, the DES multi-dimensional parameterization provides an identification signature that is highly unique and has demonstrated high levels of immunity from interferents, providing significant practical value for high-specificity material identification.

Ammonium nitrate (AN) and urea nitrate (UN) are both components commonly used in IEDs and the ability to reliably detect these chemicals is key to finding, identifying and defeating IEDs. AN and UN are complicated materials, having a number of different phases and because they are molecular crystals, there are a number of different types of interactions between the constituent atoms which must be characterized in order to understand their DES behavior. Ab initio calculations were performed on both AN and UN for various rovibrational states up to $J' \leq 3$ and validated experimentally, demonstrating good agreement between theory and experiment and the very specific responses generated.

9454-7, Session 2

Using a blackboard architecture or expert system to identify obfuscated targets from symptoms

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

A variety of techniques exist for enhancing or inferring the existence and characteristics of an obscured or partially concealed target. Many of these techniques attempt to infer the remainder of the target from a portion of the target that is identified or from imagery that is blurred or two low resolution to make a direct identification.

Targets, however, may be completely blocked from view, presenting nothing to enhance and no image area to extend inferentially. This may occur due to intentional acts by the target (or others acting to conceal the target), due to terrain features, weather factors or for other reasons. Despite the difficulty, concealed (particularly intentionally) targets may be the most important to detect. A target that is able to close a significant distance without detection reduces or eliminates the ability to react and take defensive measures.

This paper proposes a technique for using a Blackboard Architecture or expert system to infer a target's existence from symptoms. The Blackboard and expert system approaches are very similar, with the key difference between them being the Blackboard approach's ability to take actions as part of the identification and classification process, while the expert system simply passively analyzes data. Both systems look at detectable symptoms of target presence (such as maneuvers of other units, water and soil deformation, etc.) to infer the presence and classification of a target within a constrained area. The paper discusses the differences between the prospective outcomes and risks presented by the two approaches (Blackboard Architecture and expert system) before concluding with a discussion of prospective future work.

9454-8, Session 2

Efficiency of using the spectral dynamics analysis for pulsed THz spectroscopy of both explosive and other materials

Vyacheslav A. Trofimov, Svetlana A. Varentsova, Lomonosov Moscow State Univ. (Russian Federation)

One of the modern problems arising in the detection and identification of substances is a development of criteria for the assessment of a presence of explosive (or other dangerous substance) fingerprints in investigating THz signals reflected from a sample. Obviously, criteria depend on using method for the detection and identification of the substance. Taking into account on our previous experience, we use for a solution of this problem the SDA method (method of the spectral dynamics analysis).

In this report we show that the SDA method allows us to identify the explosive under real conditions. We use our approach for the identification of sample with complicated shape. This situation takes place for the PWM C4 explosive, for example. Another case under consideration is the compound explosive. We consider also the detection and identification drugs, semiconductors and harmless substance. Part of our attention is attracted to influence of opaque materials on the detection and identification if we use well-known method based on spectrum analysis. We show that this method is non-applicable for the identification of substance under real conditions. The SDA method allows us to detect the substance for any conditions under consideration.

9454-9, Session 3

Fuzzy logic based sensor performance evaluation of vehicle mounted metal detector systems

Canicious G. Abeynayake, Defence Science and Technology Organisation (Australia)

This paper proposes a fuzzy logic-based expert system for experimental data analysis and fitness evaluation of military and civilian landmine/IED detection equipment in operational scenarios. The proposed framework also predicts sensor performance based on the experimental data coupled with expert knowledge in this field. This new framework has been tested on a metal detector array evaluation and the results show a good agreement of the predicted results with experimental data points.

9454-10, Session 3

Explosive hazard detection using sensor fusion and multiple kernel learning with downward-looking GPR and EMI sensor data

Anthony Pinar, Michigan Technological Univ. (United States); Matthew P. Masarik, Jack Kelly, Michigan Tech Research Institute (United States); Timothy C. Havens, Michigan Technological Univ. (United States); Joseph W. Burns, Brian T. Thelen, Michigan Tech Research Institute (United States); John Becker, Michigan Technological Univ. (United States)

This paper explores the effectiveness of an anomaly detection algorithm for downward-looking ground penetrating radar (GPR) and electromagnetic inductance (EMI) data. Threat detection with GPR is challenged by high responses to non-target/clutter objects leading to a large number of false alarms (FAs) and since the responses of target and clutter signatures are so similar classifier design is not trivial. We suggest a method based on a Run Packing (RP) algorithm to fuse GPR and EMI data into a composite confidence map to improve detection as measured by the area-under-ROC (AUR) metric. We perform an empirical sensitivity analysis on a constant false-alarm-rate (CFAR) prescreener by adjusting its spatial parameters, as well as examine the value of a multiple kernel learning (MKL) support vector machine (SVM) classifier using image features such as histogram of oriented gradients (HOG), local binary patterns (LBP), and local statistics. Experimental results on government furnished data show that use of our proposed fusion and classification methods improve the AUR when compared with the results from individual sensors and a single kernel SVM classifier.

9454-11, Session 3

Extended-range electromagnetic induction sensor concepts

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

Typically, electromagnetic sensors are applied using one of two modalities to detect buried or obscured targets: 1) lower frequency electromagnetic induction (EMI) sensors that enable detection of targets in the near-field; and 2) higher frequency wave propagation sensors (such as forward looking or ground penetrating radar) that enable detection of targets in the far-field. Each modality has advantages and limitations. EMI sensors enable deep penetration of overburden or structures that may obscure a target; however, range is limited due to the rapid decay of the near-field. Wave propagation sensors enable detection at much greater standoffs; however, penetration into ground or structures is limited due to rapid attenuation of the propagating wave through lossy materials. In this paper, we present several concepts for enhancing the range capabilities of EMI sensors to provide both penetration and standoff capabilities. These concepts include higher frequency operation as well as higher power output transmitters. Because EMI sensors can produce magnetic field excitation along three orthogonal axes (by contrast propagating systems are limited to two transmitter polarizations), the ability to extend the EMI modality into greater standoff distances could enable not only better penetration, but also better target characterization for forward looking, side looking, or deep search operating modes.

9454-12, Session 3

Wideband electromagnetic interrogation of buried explosive hazards using 3D array

Gregory Schultz, Jonathan S. Miller, Chet Bassani, Peter Lorenz, Joe Keranen, White River Technologies, Inc. (United States)

In the often hostile, highly variable and clutter-ridden environment along roadways current buried explosive hazards (BEH) are challenging both vehicle-mounted and dismounted soldier-based clearance operations. The improvised nature of re-used munitions and detonation devices as well as the variability in BEH constituents drives the need for new technologies to fill the gaps of current route clearance methods. Recent advances in electromagnetic induction sensing offer several new capabilities that can help to extend our current capability. Specifically, we are developing a new sensor prototype array that provides rich spatial, temporal and spectral information to offer high resolution detection and characterization capabilities. We present aspects of our current work to leverage several of these advanced technologies to demonstrate a modular forward-mounted BEH detection system for integration within the Route Clearance Squad. We demonstrate an approach that applies multi-frequency and multi-axis EMI hardware to enable detection of a wide array of BEH and associated main charge constituents.

9454-13, Session 3

Munitions detection and discrimination on-the-move: dynamic EMI classification methods and potential in CONUS and OCONUS applications

Gregory Schultz, Jonathan S. Miller, Joe Keranen, Fridon Shubitidze, White River Technologies, Inc. (United States)

The implementation of new advanced electromagnetic induction (EMI) sensor surveys at sites containing unexploded ordnance (UXO) and explosive remnants of war (ERW) is an effective method for accurate mapping, but also for discriminating clutter from targets of interest. We have developed a next generation set of advanced EMI sensors, which combine the mapping capabilities of previous digital geophysical survey instruments with the high-resolution discrimination and classification capabilities of advanced characterization arrays. Here we present results from recent field tests demonstrating the detection and classification capabilities of two advanced systems: one configured as a towed array and the other as a man-portable system. By enabling high-resolution mapping, as well as discrimination and classification of munitions and explosives of concern (MEC), these systems provide a significant advancement in geophysical survey capabilities over those of current industry workhorse instruments, particularly for sites containing large quantities of non-hazardous clutter. By integrating the detection, clutter rejection, and UXO/MEC classification stages in one survey, the new dynamic discrimination methods improvements are realized through a reduction in the number of excavations required for scrap/clutter, a reduction in the total survey time

required for detection and classification, and superior quality control due to the use of a single sensor for detection and classification.

9454-14, Session 4

Buried threat detection using a handheld ground penetrating radar system

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

In this work, we explore the efficacy of two buried threat detectors on handheld data. The first algorithm is an energy-based algorithm, which computes how anomalous a given A-scan measurement after it is normalized according to its local statistics. It is based on a commonly used prescreener for the Husky Mounted Detection System (HMDS). In the HMDS setting measurements are sampled on a crosstrack-downtrack grid, and sequential measurements are at neighboring downtrack locations. In contrast, in the handheld setting sequential scans are often taken at neighboring crosstrack locations, and neighboring downtrack locations can be hundreds of scans away. In order to include both downtrack and crosstrack information, we compute local statistics over a much larger area than in the HMDS setting. The second algorithm is a shape-based algorithm. Shape Invariant Feature Transform (SIFT) features, which capture the gradient distributions of local patches, are extracted and used to train a non-linear Support Vector Machine (SVM). We found that in terms of AUC, the SIFT-SVM algorithm results in a 2.2% absolute improvement over the energy-based algorithm, with the greatest gains seen at lower false alarm rates.

9454-15, Session 4

Multiple instance dictionary learning for subsurface object detection using handheld EMI

Alina Zare, Univ. of Missouri-Columbia (United States); Brendan Alvey, Univ. of Missouri (United States) and Univ. of Missouri-Columbia (United States); Matthew Cook, Dominic K. Ho, Univ. of Missouri-Columbia (United States)

A dictionary learning approach for subsurface object detection using handheld electromagnetic induction (EMI) data is presented. A large number of unsupervised and supervised dictionary learning methods have been developed in the literature. However, the majority of these methods require data point-specific labels during training. In the application to subsurface object detection, often the specific training data samples that correspond to target and non-target are not known and difficult to determine manually. In this paper, a dictionary learning method that addresses this issue using the multiple instance learning techniques is presented. Results are shown on real EMI data sets.

9454-16, Session 4

Phase response of 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)

In this paper the phase response and return loss notch of a metal/anomaly detector design that operates in the high to very high frequency range is studied. 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 for detector performance can be accomplished by monitoring both the depth of the notch and the phase response. It has been experimentally observed that there are three regions of interest relative to the notch and phase response of the detector. One is at the frequency where the phase response is on a near vertical line of substantial phase shift and the notch is near its deepest depth. The second and third are at slightly higher and lower frequencies, where the slope of the phase shift line is reduced and the notch is still deep, but slightly removed from the frequency of maximum depth. As would be expected, initial experimentation indicates that the region of maximum detection performance, in terms of detection distance, occurs when the phase response is at the center of the near vertical phase shift response near the location of the deepest notch. However, there may be advantages to the other two regions, since the response is more stable and less prone to false alarms. Performance results for various combinations of phase response and notch depth will be shown.

9454-17, Session 5

A probabilistic framework for comparing multi-modality buried threat detection systems with dynamic velocity and sensor activity

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

Many remote sensing modalities have been developed for buried threat detection, each one offering its own relative advantages over the others. There has therefore been interest in combining several modalities into a single detection platform that benefits from the advantages of each constituent sensor, without suffering from their weaknesses. Traditionally this involves collecting data continuously on all sensors and then performing data, feature, or decision level fusion. While this is effective for lowering false alarm rates, this strategy neglects the potential benefits of a more general system-level fusion. Such a fusion can involve dynamically changing which modalities are in operation. For example, a large standoff modality such as a forward-looking infrared (FLIR) camera can be employed until an alarm is encountered, at which point a high performance (but short standoff) sensor, such as ground penetrating radar (GPR), is employed. Because the system is dynamically changing its rate of advance and sensors, it becomes difficult to evaluate the expected false alarm rate and advance rate. In this work a probabilistic model is proposed that can be used to estimate these quantities based on a provided operating policy. In this model the system consists of a set of states (e.g., sensors employed) and conditions encountered (e.g., alarm locations). The predictive accuracy of the model is evaluated using a collection of collocated FLIR and GPR data and the results indicate that the model is effective at predicting the desired system metrics.

9454-18, Session 5

Ground vehicle based LADAR for standoff detection of road-side hazards

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In recent years, the number of commercially available LADAR (also referred to as LIDAR) systems have grown with the increased interest in ground vehicle robotics and aided navigation/collision avoidance in various industries. With this increased demand the cost of these systems has dropped and their capabilities have increased. As a result of this trend, LADAR systems are becoming a cost effective sensor to use in a number of applications of interest to the Army. One such application is the standoff

detection of road-side hazards from ground vehicles. This paper will discuss detection of road-side hazards partially concealed by light to medium vegetation. Current algorithms using commercially available LADAR systems for detecting these targets will be presented, along with results from relevant data sets. Additionally, optimization of commercial LADAR sensors and/or fusion with radar will be discussed as ways of increasing detection ability.

9454-19, Session 5

Airborne thermal infrared hyperspectral imaging of buried objects

Marc-André Gagnon, Philippe Lagueux, Pierre Tremblay, Simon Savary, Vincent Farley, Éric Guyot, Martin Chamberland, Telops (Canada)

Characterization of hazardous lands using ground-based techniques can be very challenging. For this reason, airborne surveys are often preferred. The use of thermal infrared imaging represents an interesting approach as surveys can be carried out under various illumination conditions and that the presence of buried objects typically modify the thermal inertia of their surroundings. In addition, the burial or presence of an IED will modify the particle size, texture, moisture and mineral content of a small region around it. All these parameters might lead to emissivity contrasts which will make thermal contrast interpretation very challenging. In order to illustrate the potential of airborne thermal infrared hyperspectral imaging for buried IED characterization, various metallic objects were buried in a test site prior to an airborne survey. Airborne hyperspectral images were recorded using the targeting acquisition mode, a unique feature of the Telops Hyper-Cam Airborne system which allows recording of successive maps of the same ground area. Temperature-emissivity separation (TES) was carried out on individual acquisitions and the hyperspectral map obtained upon averaging. The improvement on signal-to-noise ratio and detection upon averaging of the different acquisitions will be presented.

9454-20, Session 5

Extended adaptive mutation operator for training an explosive hazard detection prescreener in forward looking infrared imagery

Ravinder Singh, Stanton R. Price, Derek T. Anderson, Mississippi State Univ. (United States)

A major problem when using forward looking (FL) imagery for explosive hazard detection (EHD) is that FL cameras see a large part of the scene, both on and off road. Even if a technology such as a road detector is used, one is still confronted with finding and subsequently discriminating targets versus clutter on the road and road side. When developing an automated system for FL-EHD, it is often the case that one engages in the use of a pre-screener to find regions of interest (ROI) versus looking for tragets in an inefficient brute force fashion (at every possible translation, rotation, and scale). In this article, we explore the role of genetic algorithms, specifically with respect to adaptive mutation, for learning the parameters of a FL-EHD pre-screener in infrared imagery. Currently, our pre-screener consists of many free parameters that are empirically chosen by a researcher. These parameters are learned herein using the proposed optimization technique and the performance of the system is measured using receiver operating characteristic (ROC) curves on data obtained from a U.S. Army test site that includes a variety of target types buried at varying depths and from different times of day.

9454-21, Session 5

Design of a buried explosive hazard pre-screener in forward looking imagery based on shearlet filtering and image post-processing

Stanton R. Price, Derek T. Anderson, Mississippi State Univ. (United States); James M. Keller, Univ. of Missouri-Columbia (United States)

A major difficulty in designing an automatic explosive hazard detection (EHD) system in forward looking (FL) imagery is the robust and efficient detection of regions of interest (ROI) that warrant further investigation. FL-EHD is particularly challenging, versus a downward looking technology, because a camera sees everything in the scene, on- and off-road. While off-road can be somewhat mitigated through various mechanisms, such as road masks or a road detector, on-road obstacles still have to be addressed. A brute force strategy is infeasible for such an application as a vehicle equipped with such a sensor requires advanced standoff capabilities, a low false alarm rate, and real-time processing to achieve a goal such as route clearance or target avoidance. Herein, we discuss the design of a new pre-screener based on Shearlet filtering and image post-processing that lets us exploit important characteristics of targets in FL imagery. Performance is assessed 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.

9454-22, Session 6

Near real-time, on-the-move multisensor integration and computing framework

Chris Burnette, Matt Schneider, EOIR Technologies (United States); Sanjeev Agarwal, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Diane Deterline, Chris Geyer, EOIR Technologies (United States); Chung D. Phan, U.S. Army RDECOM CERDEC NVESD (United States); Richard M. Lydic Jr., U.S. Army Night Vision & Electronic Sensors Directorate (United States); Kevin K. Green, Bruce Swett, EOIR Technologies (United States)

Implanted mines and improvised explosive devices (IEDs) are a persistent threat to Warfighters. Current Army countermine/counter-IED missions for route clearance include the use of ground penetrating radar (GPR) sensor mounted on a blast-resistant vehicle to identify and neutralize mines and IEDs. Route clearance is a dangerous and time-consuming process that impacts the tempo of operational missions. Improving the effectiveness and efficiency of route clearance patrols (RCPs) is vital to Army operational missions.

Vehicle-based sensors such as electro-optical and infrared (EO/IR) devices can be used to identify potential threats in near real-time (NRT) to support route clearance missions. Potential threats identified by the vehicle-based sensors – such as disturbed earth, changes in AO since last mission, and suspicious activities in the AO – can be used to improve the use of the GPR in locating mines and IEDs. The MOVERS (Micro-Cloud for Operational, Vehicle-Based EO-IR Reconnaissance System) is a vehicle-based system that ingests and processes video and imagery data captured from forward-looking EO/IR and thermal sensors, and also generates target/feature alerts, using the Video Processing and Exploitation Framework (VPEF) "plug and play" video processing toolset.

The MOVERS Framework provides an extensible, flexible, and scalable computing/integration GOTS framework that enables the capability to add more vehicles, sensors, processors or displays, and a service architecture that provides low-latency raw video and metadata streams as well as a command and control interface. Functionality in the framework is exposed

through the MOVERS SDK which decouples the implementation of the service and client from the specific communication protocols.

9454-23, Session 6

Near real-time, on-the-move software PED using VPEF

Kevin K. Green, Chris Geyer, Chris Burnette, EOIR Technologies (United States); Sanjeev Agarwal, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Bruce Swett, EOIR Technologies (United States); Chung D. Phan, Richard M. Lydic Jr., U.S. Army Night Vision & Electronic Sensors Directorate (United States); Diane Deterline, EOIR Technologies (United States)

The scope of the Micro-Cloud for Operational, Vehicle-Based EO-IR Reconnaissance system (MOVERS) development effort, managed by Night Vision Electronic Sensors Directorate (NVESD), is to develop, integrate, and demonstrate new sensor technologies and algorithms that improve IED and mine detection using efficient and effective exploitation and fusion of sensor data and target cues from existing and potential future Route Clearance Package (RCP) sensor systems.

Unfortunately, the majority of forward looking full-motion video (FMV) and computer vision processing, exploitation, and dissemination (PED) algorithms are often developed using proprietary, incompatible software. However, by using a framework which standardizes the input and outputs, algorithms can be made interchangeable, interoperable and flexible. With PED algorithms supporting standardized inputs, sensors can be evaluated using the algorithms without modifying the algorithm's software itself.

EOIR developed the Video Processing & Exploitation Framework (VPEF), a GOTS framework, to be able to rapidly integrate, standardize, and test computer vision algorithms, and to provide standardized interfaces for exploitation software, including input video formats, sensor metadata, and detected objects.

Under the MOVERS effort, EOIR developed a vehicle-based computing framework within the MOVERS framework and integrated it with VPEF and other non-VPEF-based processing algorithms. VPEF was further extended for near real-time (NRT) detection processing (i.e., VPEF RT) to support RCP patrol. VPEF-RT uses a video processing pipeline structure consisting of individual modules, also known as plug-ins, which can be selected from a library of FMV and computer vision plug-ins, making the framework flexible. PED algorithms were modified to support VPEF-RT which allowed the algorithms to be tested using a variety of input sensors.

With the inputs and outputs standardized, algorithms were able to be interchanged to compare the performance of each as well as to run the algorithms together, utilizing the benefits of each algorithm. Algorithm performance was also tested to ensure real-time on-the-move processing could be achieved. VPEF-RT was shown to be capable of handling real-time on-the-move processing and provided a standardized interface for PED algorithms. PED algorithms were ported quickly and successfully to VPEF-RT and tested using multiple visible color and thermal (FLIR) sensors.

Finally, EOIR is investigating the added value of incorporating accelerated processing techniques such as leverage GPU acceleration through CUDA/OpenCL VPEF plugin developments to further maximize algorithm performance and speed in execution.

9454-25, Session 6

Real-time buried IED detection and cueing capability in VPEF environment

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In this paper, we present a vehicular buried IED (Improvised Explosive Device) detector developed over the past several years ([1], [2], [3] and [4]), and its latest implementation and integration in VPEF (Video Processing and Exploitation Framework) environment. During the buried IED emplacement, the surface soils are inevitably disturbed, resulting in different heat absorption and dissipation rate as compared to the surrounding soils. The temperature difference between buried IED surface soil and surrounding soil produces unique thermal signatures that can be used for the detection of buried IEDs through MWIR and LWIR cameras mounted on the military vehicles.

With a vehicular platform at a long standoff distance, the camera grazing angle is often very small. In this setting, buried IEDs appear as ovular shapes in thermal imagery, which can be treated as the signature of buried IEDs. In our system, a baseline module is developed to identify potential buried targets, either true or false, with ovular shapes using anomaly-based detection algorithms. Its main task is to detect all potential targets, which will be further processed for target discrimination and declaration.

To discriminate true targets from false alarms, a suite of false alarm mitigators are developed. Since false alarms show many different characteristics in their thermal signatures, we have developed a suite of false alarm mitigators (FAMs) in our buried IED detection system. Each FAM is designed to reject false alarms from a particular perspective. It was found that false alarms often come from background clutters such as tire tracks and rough soils in the wash areas, and their spatial textures in thermal imagery are different from those associated with true buried targets. Therefore a number of statistical spatial distribution and randomness analysis methods are developed to separate the true targets from false alarms.

To further reduce the false alarms, we have also developed a multi-target track analysis method. In this approach, the tracks of targets (true and false) are formed over a number of image frames. In addition, the vehicle track is also estimated and mapped to the corresponding images through the camera perspective projection. Both target tracks and vehicle track are then statistically analyzed for discrimination. Since true target tracks are statistically similar to the vehicle track, we apply the statistical uniformity hypothesis test for the rejection of false alarms.

All of the detection algorithms have been implemented in C/C++ as VPEF plugins. The design of each plugin has a set of well-defined input and output variables. They can be executed in VPEF multi-thread environment for realtime buried IED detection. Moreover, following GStreamer standard, these plugins can interact with different plugins developed by third parties. With this interoperability capability, our buried IED detection system is flexible and scalable.

In this paper, we will also present the test results of our buried IED detection system operating in VPEF environment. A number of different datasets collected in different environments are used to evaluate the system detection performance.

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9454-26, Session 7

Multi-scale HOG prescreening algorithm for detection of buried explosive hazards in FL-IR and FL-GPR data

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A sliding window based prescreening algorithm, utilizing multi-scale histogram of oriented gradient (HOG) features and a linear support vector machine (SVM) classifier, for detection of buried explosive hazards in forward-looking infrared (FL-IR) imagery is presented. This algorithm is compared to a previously published FL-IR prescreening algorithm which uses an ensemble of local, dual-sliding window RX anomaly detectors. The multi-scale HOG prescreening approach has higher computational complexity, but improves detection of low-contrast and obscured target signatures. Results are presented on several large data sets collected at US Army test sites. These collections span several days, and include imagery from both long-wave and mid-wave infrared cameras at multiple standoff distances captured at different hours of the day and different times of the year. We also investigate how the prescreener model trained on imagery from one IR camera can be adapted to imagery from a new IR camera. This adaptation is performed using only the intrinsic and extrinsic parameters of the new camera. It does not require new data collection on calibration lanes. The performance of the adapted classifier is compared to that of the classifier when trained directly on the new imagery.

9454-27, Session 7

An application of log-Gabor filter on road detection in arid environments for forward looking buried object detection

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One of the crucial functions in the forward looking buried object detection method is to anticipate the directional change of the operating vehicle. Since the operating vehicle is driven on the road, the prominent way to anticipate the directional change is to detect the road that lies in front of the vehicle. It is advantageous to detect the road at a great distance because the imaging system would have greater amount of time to process the scene. However, using only color imagery, detecting unpaved roads in arid environments has proven to be a complicated task, and even more so to do it at a great distance. The complication is due to the fact that the texture of the road at a close distance is drastically different from that at a far distance. Furthermore, it is impractical to train multiple road models to handle the varying road texture and distances.

In this paper, we proposed the use of the Log-Gabor Filter (LGF) to enhance our road detection system. The LGF can be used to suppress the road-like pixels in the image. By filtering the unpaved road images with varying scales and orientations of LGF and a combination of basic image processing techniques, evidence images of the road are created. Each evidence image is a binary image where value one on any pixel represents the evidence of road at that pixel, otherwise the value will be zero. However, the maximum distance for generating evidence of the road varies for each image. Therefore, the road model is utilized. Using the least square method, the road model is optimized to fit the support of the road presented in each image. By specifying the length of the road on the optimized model, the distance of road detection is also specified. Thus, utilizing the LGF and the road model allows our system to detect the road as far as forty meters.

9454-28, Session 8

A method for detecting ultra-low quantities of explosives with use a picosecond laser FAIMS analyzer

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A method for detecting ultralow quantities of explosives in air and traces using a state-of-the-art picosecond chip Nd^{3+}:YAG laser has been elaborated. The method combines field asymmetric ion mobility spectrometry (FAIMS) with laser ionization of air samples and laser desorption of analyzed molecules from examined surfaces. Radiation of wavelength 266nm, pulse time 300ps, pulse energy 40–150?J, frequency 100–300Hz was used. The twin-pass optical scheme was developed for the laser ion source. Parameters of the laser ion source have been specially optimized for the use a picosecond ionization mode. The dependences on frequency, pulse energy, peak intensity, and average power for trinitrotoluene (TNT), cyclotrimethylenetrinitramine (RDX), and glyceryl trinitrate (NG) were investigated. It was shown that the optimal peak intensity should be 2 MW/cm2 or higher; at lower peak intensities the increase of the average laser power in the interval 5–15 mW enhanced the ion signal. The detected ion signals for all explosives were shown to be threefold higher for picosecond excitation in comparison with use a nanosecond laser of the same average power.

The laser desorption regime was developed where a laser beam exiting the detector after removal of a special plug was used. The results of TNT, RDX, NG detection are presented.

The chip Nd^{3+}:YAG laser has a small emitter and a consumed electric power of 25 W. The estimated detection threshold of the prototype equals 10-15 g/cm3. The results are promising in terms of the development of a highly sensitive, portable laser explosive detector.

9454-29, Session 8

Surface enhanced Raman scattering (SERS) detection of ammonium nitrate (AN) samples fabricated using drop-on-demand inkjet technology

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The requirement to detect hazardous materials at standoff distances has led to the development of laser based hazard detection systems with immediate application to the US military, national security agencies, and environmental response teams. In particular, common explosives and improvised explosive devices (IED) materials have motivated research efforts toward detecting trace quantities on multiple surfaces (textiles, metals, plastics, natural products, people). Non-destructive detection techniques can detect trace quantities of explosive materials; however, they are generally not very effective in the presence of a complex chemical background. One spectroscopic technique gaining increased attention for detection is SERS.

Despite the current operational challenges of measuring trace hazard samples with Raman, research efforts continue to improve these standoff detection systems. One means by which this is achieved is through properly training the system to accurately identify and quantify hazardous materials. One such material gaining more attention is Ammonium nitrate (AN). AN has many agricultural applications, however it can also be used in the fabrication of homemade explosives (HMEs). In this report, accurate AN

sample preparation for the evaluation of standoff hazard detection systems will be discussed as applied to several different common material surfaces (e.g. wood, human hair, textiles, metals, plastics).

9454-30, Session 8

Detection of homemade explosives using Raman excitation at 1064 nm

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Raman spectroscopy is a powerful tool for obtaining molecular structure information of a sample. While Raman spectroscopy is a common laboratory based analytical tool, miniaturization of opto-electronic components has allowed handheld Raman analyzers to become commercially available. These handheld systems are utilized by Military and Bomb squad operators tasked with rapidly identifying explosives in the field, sometimes in clandestine laboratories. However, one limitation of many handheld Raman detection systems is strong interference caused by fluorescence of the sample or underlying surface which obscures the characteristic Raman signature of the target analyte.

Homemade explosives (HMEs) are produced in clandestine laboratories, and the products under these conditions are typically contaminated with degradation products, contaminants, and unreacted precursors. These contaminations often will have strong fluorescence. In this work, Raman spectra of both commercial explosives and HMEs were collected using a handheld Raman spectrometer with a 1064 nm excitation laser. While Raman scattering generated by a 1064 nm laser is inherently less efficient than excitation at shorter wavelengths, high quality spectra were easily obtained due to significantly reduced fluorescence of HMEs.

9454-31, Session 9

Clutter and target discrimination in forward-looking ground penetrating radar using sparse structured basis pursuits

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Forward-looking ground penetrating radar (FLGPR) is a remote sensing modality that has recently been investigated for buried threat detection. FLGPR offers greater standoff than other downward-looking modalities such as electromagnetic induction and downward-looking GPR, but it suffers from high false alarm rates due to surface and ground clutter. A stepped frequency FLGPR system consists of multiple radars with varying polarizations and bands, each of which interacts differently with subsurface materials and therefore might potentially be able to discriminate clutter from true buried targets. However, it is unclear which combinations of bands and polarizations would be most useful for discrimination and how to fuse them. This work applies sparse structured basis pursuit, a supervised statistical model which searches for sets of bands that are collectively effective for discriminating clutter from targets. The algorithm works by trying to minimize the number of selected items in a dictionary of signals; in this case the separate bands and polarizations that make up the dictionary elements. A structured basis pursuit algorithm is employed to gather groups of modes together in collections to eliminate whole polarizations or sensors. The approach is applied to a large collection of FLGPR data for data around emplaced target and non-target clutter. The results show that a sparse structure basis pursuits outperforms a conventional CFAR anomaly detector, while also pruning out unnecessary bands of the FLGPR sensor.

9454-32, Session 9

Deep belief networks for false alarm rejection in forward-looking ground-penetrating radar

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

Explosive hazards are one of the most deadly threats in modern conflicts. The U.S.~Army is interested in a reliable way to detect these hazards at range. A promising way of accomplishing this task is using a forward-looking ground-penetrating radar (FLGPR) system. Recently, the Army has been testing a system that utilizes both L-band and X-band radar arrays on a vehicle mounted platform. Using data from this system, we sought to improve the performance of a constant false-alarm-rate (CFAR) prescreener through the use of a deep belief network (DBN). DBNs combine unsupervised pre-training with supervised fine-tuning to generate low-dimensional representations of high-dimensional input data. DBNs have also been shown to perform exceptionally well at detecting anomalies. We sought to take advantage of these two properties by training a DBN on the features of the CFAR prescreener's false alarms (FAs) and then use that DBN to separate FAs from true positives. Our analysis shows that this method improves the detection statistics significantly. By training the DBN on a combination of image features, we were able to significantly increase the probability of detection while maintaining a nominal number of false alarms per square meter. Our research shows that DBNs are a good candidate for improving detection rates in FLGPR systems.

9454-33, Session 9

An Apodization Approach for Processing Forward-Looking GPR for Buried Target Detection

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A forward-looking and -moving ground-penetrating radar (GPR) acquires data that can be used for explosive hazard detection. As the platform moves forward, the sensor can acquire and form a sequence of images for a common spatial region. Due to the near-field nature of relevant collection scenarios, the point-spread function (PSF) varies significantly as a function of the spatial position, both within the scene and relative to the sensor platform. This variability of the PSF causes computational difficulties for matched-filter and related processing of the full video sequence. One approach to circumventing this difficulty is to coherently or incoherently integrate the video frames, and then perform detection processing on the integrated image. Here, averaging over the space- and motion-variant nature of the PSFs for each frame causes the PSF for the integrated image to appear less space-variant. Another alternative---and the one we investigate in this paper---is to transform each image from the conventional (range, cross-range) coordinate system to a (range, sine-angle) coordinate system for which the PSF is approximated as spatially invariant. Then, the transformed video data can be processed with a computationally feasible matched filter to identify potential targets in the video sequence. To evaluate the relative advantages of this procedure, we will compare the performance of this video processing with the detection performance from the coherently- or incoherently-integrated image.

9454-34, Session 9

A synthetic aperture acoustic prototype system

Robert H. Luke III, Steven S. Bishop, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Aaron Chan, U.S. Army RDECOM CERDEC NVESD (United States); Peter M. Gugino, Thomas P. Donzelli, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Mehrdad Soumekh, Soumekh Consultant (United States)

A novel quasi-monostatic system operating in a side-scan synthetic aperture acoustic (SAA) imaging mode is presented. This research project's objectives are to explore the military utility of outdoor continuous sound imaging of roadside foliage and target detection. The acoustic imaging method has several military relevant advantages such as being immune to RF jamming, superior spatial resolution as compared to 0.8-2.4 GHz ground penetrating radar (GPR), capable of standoff side and forward-looking scanning, and relatively low cost, weight and size when compared to GPR technologies. The prototype system's broadband 2-17 kHz LFM chirp transceiver is mounted on a manned all-terrain vehicle. Targets are positioned within the acoustic main beam at slant ranges of two to seven meters and on surfaces such as dirt, grass, gravel and weathered asphalt and with an intervening metallic chain link fence. Acoustic image reconstructions and signature plots result in means for literal interpretation and quantifiable analyses.

9454-35, Session 9

Explosive hazard detection using MIMO forward-looking ground-penetrating radar

Darren Shaw, Univ. of Missouri (United States); Dominic K. Ho, Univ. of Missouri-Columbia (United States); Kevin Stone, Univ of Missouri (United States); James M. Keller, Mihail Popescu, Univ. of Missouri-Columbia (United States); Derek Anderson, Mississippi State Univ. (United States); Robert H. Luke III, Brian P. Burns, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

This paper proposes a statistical and machine learning algorithm for subsurface object detection on the multiple-input-multiple-output (MIMO) forward-looking ground-penetrating radar (FLGPR). The proposed system utilizes an anomaly detection prescreener to identify potential object locations. We then weigh the confidence or reject the alarms by comparing the responses of different polarizations of the MIMO FLGPR array. The fast Fourier transform (FFT) of the data at the candidate-alarm locations is extracted in order to form a spatial frequency feature set. A Support Vector Machine (SVM) is then employed to classify potential targets and reduce false alarms. Experimental results using the data collected at an US Army test site show the effectiveness of using the MIMO FLGPR and multiple polarizations for the detection of explosive hazards.

9454-36, Session 9

Advanced processing of standoff sensor data for detecting explosively formed penetrators

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Side-attack weapons are being used in a number of munitions systems to defeat armor, masonry, and concrete targets by launching from distance and attacking from oblique angles. The ability to detect and discriminate these munitions and similarly Misznay-Schardin effect-based devices rely on the effective use of vehicle-based standoff sensor technologies such as forward-looking and ground-penetrating radar, LiDAR, and other electromagnetic or electro-optical methods. We are developing a robust set of detection and discrimination features for the current suite of Army sensor assets to reduce the false alarm rates due to ubiquitous and heterogeneous roadside clutter environments. We utilize physics-based investigations of propagation and scattering phenomenology as well as adaptations of our airborne and space-based processing and feature extraction methods to optimize the information for detection. The results of our work are driving the design of tailored sensor systems as well as providing the foundation for automated target detection and recognition methods for route clearance.

9454-37, Session 10

Automatic target detection and discrimination algorithm applicable to ground penetrating radar data

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This paper focuses on development of a new automatic target recognition (ATR) algorithm applicable to GPR data to detect targets of interest and to discriminate them from clutter found in realistic scenarios. Three approaches for ATR are presented: a probabilistic approach; an artificial neural network with direct data input; and, an image processing based technique. The proposed ATR algorithms have been evaluated using a data set acquired by a vehicle-mounted NIITEK GPR array.

9454-38, Session 10

Design and validation of inert homemade explosive simulants for ground penetrating radar

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The Canadian Armed Forces (CAF) identified a requirement for inert simulants to act as improvised, or homemade, explosives (IEs) when training on, or evaluating, ground penetrating radar (GPR) systems commonly used in the detection of buried landmines and improvised explosive devices (IEDs). During routine training, GPR operators are at times tested against surrogate IEDs consisting of containers filled with locally available materials. Unfortunately, such ad hoc solutions can generate non-representative GPR signals, which in turn may lead to poorer operator training and performance against the targets of interest. In response, Defence R&D Canada (DRDC) initiated a project to develop IE simulant formulations using commonly available inert materials. These simulants are intended to approximate the expected GPR response of common IEs, in particular ammonium nitrate, ammonium nitrate/fuel oil, and ammonium nitrate/aluminum. The complex permittivity over the range of electromagnetic frequencies relevant to standard GPR systems was measured for bulk quantities of these three IEs that had been fabricated at DRDC Suffield Research Centre. Following these measurements, published literature was examined to find benign materials with both a similar complex permittivity, as well as other physical properties deemed desirable - such as low-toxicity, thermal stability, and commercial availability - in order to select candidates for subsequent simulant formulation. Suitable simulant formulations were identified for all three IEs, with resulting complex permittivities measured to be within acceptable

limits of target values. These IE formulations will now undergo end-user trials with CAF operators in order to confirm their utility. This paper outlines the development program, simulant design, and validation results.

9454-39, Session 10

Deep convolutional neural networks for classifying GPR B-scans

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Symmetric and asymmetric buried explosive hazards (BEHs) present real, persistent, deadly threats on the modern battlefield. Current approaches rely on highly trained operatives to reliably detect BEHs with reasonable false alarm rates using handheld Ground Penetrating Radar (GPR) and metal detectors. As computers become smaller, faster and more efficient, there exists greater potential for automatic detection techniques based on state-of-the-art machine learning approaches to aid field operatives in finding these deadly threats. Recent advancements in machine learning, specifically deep learning artificial neural networks, have led to significantly improved performance in pattern recognition tasks, such as object classification in digital images. Deep convolutional neural networks (CNNs) are used in this work to extract meaningful signatures from 2-dimensional GPR B-scans and classify threats. The CNNs skip the traditional "feature engineering" step often associated with machine learning, and instead learn the feature representations directly from the 2-D data. A Gaussian process optimization technique was used to optimize the CNN hyperparameters. A multi-antennae, handheld GPR with centimeter-accurate positioning data was used to collect shallow subsurface data over prepared lanes containing a wide range of BEHs. Several heuristics were used to prevent over-training, including cross validation, network weight regularization and "dropout." Our results show that CNNs can extract meaningful features and accurately classify complex signatures contained in GPR B-scans, complementing existing GPR anomaly detection and classification techniques.

9454-40, Session 10

GPR anomaly detection with robust principal component analysis

Matthew P. Masarik, Joseph W. Burns, Brian T. Thelen, Jack Kelly, Michigan Tech Research Institute (United States); Timothy C. Havens, Michigan Technological Univ. (United States)

This paper investigates the application of Robust Principal Component Analysis (RPCA) to ground penetrating radar as a means to improve GPR anomaly detection. The method consists of a preprocessing routine to smoothly align the ground and remove the ground response (haircut), followed by mapping to the frequency domain, applying RPCA, and then mapping the sparse component of the RPCA decomposition back to the time domain. A prescreener is then applied to the time-domain sparse component to perform anomaly detection. The emphasis of the RPCA algorithm on sparsity has the effect of significantly increasing the signal-to-clutter ratio (SCR) as compared to the original data, thereby enabling improved anomaly detection. This method is compared to detrending (spatial-mean removal) and classical principal component analysis (PCA), and the RPCA-based processing is seen to provide substantial improvements in SCR over both of these alternative processing schemes. In particular, the algorithm has been applied to both government-provided impulse and stepped-frequency GPR data and has shown significant improvement in terms of the area under the ROC curve relative to detrending and PCA.

9454-41, Session 10

A layer tracking approach to buried surface detection

Peter J. Dobbins, Joseph Wilson, Brandon Smock, Univ. of Florida (United States)

Ground penetrating radar (GPR) devices use sensors to capture a one-dimensional representation, or A-scan, of the soil and buried properties at each sampling point. Previous work uses reciprocal pointer chains (RPC) to find one-dimensional layers in two-dimensional data. We extend this work to find two-dimensional layers in three-dimensional data. We explore the application and differences of our techniques when they are applied to vehicular mounted systems versus handheld systems and their distinct detection sweep sequences. Not only can this work be used to display subsurface structure to a system operator, but we can also use changes in the subsurface structure of a local region to identify buried objects within the data. We are using Markov Logic Networks (MLN) to better understand the context of regions examined. We believe this work can increase the probability of detection and reduce false alarm rates.!

9454-42, Session 11

Target signature localization in GPR data by clustering and classification

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

Buried threat detection algorithms in Ground Penetrating Radar (GPR) measurements often utilize a statistical classifier to model target responses. There are many different targets types with distinct responses and all are buried in a wide range of conditions that distort the target signature. Robust performance of this classifier requires it to learn the distinct responses of the targets types while accounting for the variability due to the object emplacement. In this work, a method to reduce certain sources of excess variation is presented that enables a linear classifier to learn distinct templates for each target type's response despite the operational variability. The different target subpopulations are represented by a Gaussian Mixture Model (GMM). Training the GMM requires jointly extracting the patches around target responses as well as learning the statistical parameters as neither are known a priori. The GMM parameters and the choice of patches are determined by variational Bayesian methods. The proposed method allows for patches to be extracted from larger data-blocks around the target response. The patches extracted from this method improve the ROC for distinguishing targets from background clutter compared to the patches extracted using other patch extraction methods and can help improve system performance.

9454-43, Session 11

Fast 3D subsurface imaging with stepped-frequency GPR

Matthew P. Masarik, Joseph W. Burns, Brian T. Thelen, Lena Sutter, Michigan Tech Research Institute (United States)

This paper investigates an algorithm for performing 3D imaging of the subsurface using stepped-frequency GPR data. The algorithm is specifically designed for a handheld GPR and therefore accounts for the irregular sampling pattern in the data and the spatially-variant air-ground interface by estimating an effective "ground-plane" and then registering the data to the plane. The algorithm efficiently solves the 4th-order polynomial for the Snell reflection points using a fully vectorized iterative scheme. The forward operator is implemented efficiently using an accelerated nonuniform FFT (Greengard & Lee, 2004); the adjoint operator is implemented efficiently

using an interpolation step coupled with an upsampled FFT. The imaging is done as a full inverse problem, which is regularized using a sparsity constraint to reduce sidelobes and therefore improve image localization. Applying an appropriate sparsity constraint, the algorithm is able to eliminate most the surrounding clutter and sidelobes, while still rendering valuable image properties such as shape and size. The algorithm is applied to simulated data, controlled experimental data (made available by Dr. Waymond Scott, Georgia Institute of Technology), and government-provided data with irregular sampling and air-ground interface.

9454-44, Session 11

Fusion of forward-looking infrared camera and down-looking ground penetrating radar for buried target detection

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Even though Ground Penetrating Radar (GPR) systems can give alarms for buried threats autonomously, it is ultimately the operators' responsibility to decide whether the given alarm is a mine or not. To assist the operators, in this work, a novel sensor fusion framework is proposed where a forward looking long wave infrared (FL-LWIR) camera (FLIR) and a down looking GPR (Niitek) mounted on the top and on the front of a robotic system, respectively, are used.

This system collected data from a test area of 500m2, which was prepared at the IPA Defence, Ankara, Turkey. This test area was divided into four lanes, each of size 25m length by 4m width and 1m depth. Each lane was first carefully cleaned of stones and clutter and then filled with different soil types, namely fine-medium sand, course sand, sandy silt loam (medium-course silt / medium-course sand mix) and loam mix (fine silt mixed with fine gravel). In all lanes, various clutter objects and IEDs were buried at different depths and at 1meter intervals. The IEDs were designed by an expert soldier.

Two approaches are proposed to detect buried threats from the collected data. In the sequential approach, RX algorithm together with the GPS data is used to locate the anomalies in thermal images. On these suspicious regions, Histogram of Oriented Gradient (HOG) features are extracted from GPR images and are classified by SVM. In the second approach, GPR and IR based algorithms are used simultaneously and results are combined using decision level fusion. The two approaches are compared for different scenarios including different weather temperature, soil type and depth of buried targets.

9454-45, Session 11

Detection of deeply buried non-metal objects by ground penetrating radar using non-negative matrix factorization

Daniel Nabelek, Dominic K. Ho, Univ. of Missouri-Columbia (United States)

The ground penetrating radar (GPR) signal for a deeply buried non-metal object is weak and does not have a hyperbolic signature, making it difficult to detect with high confidence. This paper takes a blind source separation approach by using non-negative matrix factorization (NMF) to improve the detection of deeply buried non-metal objects. The proposed approach interprets the GPR signal return as the sum of two independent components from two different sources, the background and the object. NMF enables the separation of the object signal component from the composite and thereby improves the detection performance. Preliminary results from a test site in the United States indicate that the probability of detecting these objects is improved by more than 20% compared to the pre-screener, at a false alarm rate of 0.003/m^2.

9454-46, Session 11

Recognizing subsurface target responses in ground penetrating radar data using convolutional neural networks

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

Improved performance in the discrimination of buried threats using Ground Penetrating Radar (GPR) data has recently been achieved using features developed for applications in computer vision. These features, designed to characterize local shape information in images, have been utilized to recognize patches that contain a target signature in two-dimensional slices of GPR data. While these adapted features perform very well in this GPR application, they were not designed to specifically differentiate between target responses and background GPR data. One option to develop a feature specifically designed for target differentiation is to manually design a feature extractor based on the physics of GPR image formation. However, as seen in the historical progression of computer vision features, this is not a trivial task. Instead, this research evaluates the use of convolutional neural networks (CNNs) applied to two-dimensional GPR data. The benefit of using a CNN is that features extracted from the data are a learned parameter of the system. This has allowed CNN implementations to achieve state of the art performance across a variety of data types, including visual images, without the need for expert designed features. However, the implementation of a CNN must be done carefully for each application as network parameters can cause performance to vary widely. This paper presents results from using CNNs for object detection in GPR data and discusses proper parameter settings and other considerations.

9454-49, Session 11

Anomaly detection of subsurface objects using handheld ground-penetrating radar

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This paper develops an anomaly detection algorithm for subsurface object detection using the handheld ground penetrating radar. The algorithm is based on the Mahalanobis distance measure with adaptive update of the background statistics. It processes the data sequentially for each data sample and applies the mean-shift algorithm to generate alarm locations and detection confidences. The algorithm will be applied to process the data from two different radars, an impulse and a step-frequency, for performance evaluation.

9454-47, Session 12

Improving buried threat detection in ground-penetrating radar with transfer learning and metadata analysis

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

Ground-penetrating radar (GPR) technology has proven capable of detecting buried explosive threats. The system relies on a binary classifier that is trained to distinguish between two classes: a "target" class, encompassing many types of buried threats and their components; and a "nontarget" class, which includes false alarms from the system prescreener. Typically, the training process involves a simple partition of the data into these two classes, which allows for straightforward application of standard classifiers. However, since training data is generally collected in fully controlled environments, it includes auxiliary information about each example, such as the specific type of threat, its purpose, and its depth.

Examples from the same specific or general type may be expected to exhibit similarities in their GPR data, whereas examples from different types may differ greatly. This research aims to leverage this additional information to improve overall classification performance by fusing classifier concepts for multiple groups, and to investigate whether structure in this information can be further utilized for transfer learning, such that the amount of expensive training data necessary to learn a new, previously-unseen target type may be reduced. Methods for accomplishing these goals are presented with results from a dataset containing a variety of target types.

9454-48, Session 12

Leveraging robust principal component analysis to detect buried explosive threats in handheld ground-penetrating radar data

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

A goal of ground penetrating radar (GPR) preprocessing is to further distinguish background and clutter data from data containing explosive threats. This is often achieved by performing depth-dependent mean/standard deviation normalization, where the mean and standard deviation are computed on background/clutter data. Under the assumption that data with explosive threats has different statistical characteristics than the background/clutter, after normalization explosive threat data will have larger absolute normalized scores than the background/clutter. An underlying problem is determining which data to compute the background mean and standard deviation statistics over. Often, the background statistics are computed over a moving window, which is centered at the location of interest and has a predetermined guard band (an ignored region immediately adjacent to the location of interest). However, buried explosive threats vary considerably in their shapes and more importantly sizes? and subsequently the size of the GPR responses from these objects are considerably varied. Therefore, using a predetermined guard band is inappropriate. We examine a number of preprocessing methods which utilize Robust Principal Component Analysis (RPCA), where RPCA decomposes a data matrix into low-rank and sparse matrices. Intuitively, the low-rank matrix should capture the background data and the sparse matrix should capture the anomalous explosive threat response. We find that RPCA is able to further distinguish background/clutter from explosive threat data, and is robust to varying target sizes.

9454-51, Session 13

Tagged neutron capabilities for detecting hidden explosives

Sergei G Belichenko, Vyacheslav F Batyaev, Romeo R Bestaev, Maxim D Karetnikov, Alexander V Gavryuchenkov, Dukhov All-Russia Research Institute of Automatics (VNIIA) (Russian Federation)

No Abstract Available

9454-52, Session 14

Information surfing with the JHU/APL coherent imager

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The ability to perform remote forensics in situ is an important application of autonomous undersea vehicles (AUVs). Forensics objectives may include remediation of mines and/or unexploded ordnance, as well as monitoring of seafloor infrastructure. At JHU/APL, digital holography is being explored for the potential application to underwater imaging and integration with an AUV. In previous work, a feature-based approach was developed for processing the holographic imagery and performing object recognition. In this work, the results of the image processing method were incorporated into a Bayesian framework for autonomous path planning referred to as "information surfing." The framework was derived assuming that the location of the object of interest is known a priori, but the type of object and its pose are unknown. The path-planning algorithm adaptively modifies the trajectory of the sensing platform based on historical performance of object and pose classification. The algorithm is called "information surfing" because the direction of motion is governed by the local information gradient. Simulation experiments were carried out using holographic imagery collected from submerged objects. The autonomous sensing algorithm was compared to a deterministic sensing CONOP, and demonstrated improved accuracy and faster convergence in several cases.

9454-53, Session 14

Multiple pass collaborative search in the presence of false alarms

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This paper addresses the planning of multiple collaborative searchers that are seeking to find hidden objects (i.e. mines) in environments where the sensor detection process is prone to false alarms. In such situations it is anticipated that collaboration between searchers that are examining the same sub-regions may be used to mitigate the impact of false alarms. A standard Receiver Operator Characteristic (ROC) analysis is conducted and the mapping between a single search pass ROC curve and an equivalent multiple search pass representation within a cumulative probability space is discussed. This mapping produces an analogous family of ROC curves for an increasing number of search passes using either a first detection or multiple occurrence performance criteria. The migration of ROC operating points is analyzed as additional search passes are included within a search plan and suggests the need to coordinate search effort with operating point selection. The mapping from waiting time event probabilities to a total error performance criterion weighted according to the cumulative probabilities of missed detection and false alarm is developed. Details of its application within a search planning optimization algorithm are discussed and numerical results are provided to demonstrate the usefulness of the modeling in constructing a Pareto curve analysis of the performance tradeoff. Finally, we discuss the impact of this search planning optimization on the use of multiple autonomous agents for conducting collaborative searches.

9454-54, Session 14

Optimal relative view angles for an object viewed multiple times

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Typically, the detection of an object of interest improves as we view the object from multiple angles. For cases where viewing angle matters, object detection can be improved further by optimally selecting the relative angles of multiple views. This motivates the search for viewing angles that maximize the expected probability of detection. Although our work is motivated by applications in subsea sensing, our fundamental analysis is easily adapted for other classes of applications. The specific challenge that motivates our work is the selection of optimal viewing angles for subsea sensing in which sonar is used for bathymetric imaging.

For a fixed viewing distance to a symmetric object of interest, our goal is to

select viewing angles that maximize the expected probability of detection. We assume that the probability of detection of an object varies with viewing angle. For example, a long cylindrical object may be easier to detect when viewed from one axis rather than the other. However, we assume that the orientation of the object in the environment is unknown. If no knowledge of the orientation of the object is available, then we assume that the orientation of uniformly distributed over all angles. If instead, a preferential object orientation is known or suspected, then a different distribution can be used. In any case, we rigorously show that when an object of interest is viewed twice from a fixed distance, and that orientation of the object is uniformly distributed, then expected probability of detection is maximized when viewing angles are orthogonal. For the case of N>2 viewing angles, we rigorously show that the angular separation of pi/N radians between viewing angles satisfies the necessary conditions for optimality of expected probability of detection. Derivation of corresponding sufficient condition is on-going. Simulation results presented in the paper for various values of N provide further evidence that the angular separation of pi/N radians between viewing angles corresponds to the global maxima of the expected probability of detection.

We also consider the case that probability of detection is dependent on orientation of the sensor with respect to environmental phenomena. For subsea applications, sand-ripples are a well-known example where probability of detection varies depending on the orientation of the sensor with respect to the direction of the sand ripples. With knowledge of the direction of the sand ripples and an estimate of the probability of detection as a function of sensor orientation with respect to sand-ripples, we are able to compute the view angles that maximize expected probability of detection when orientation of the object is unknown and uniformly distributed. An interesting result of this analysis is that orthogonal viewing angles are no longer optimal. No closed-form solution is available for this case, but numerical results are easily computed for any given problem.

9454-55, Session 14

Possibilistic context identification for SAS imagery

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This paper proposes a possibilistic context identification approach for synthetic aperture sonar (SAS) imagery. SAS seabed imagery can display a variety of textures that can be used to identify seabed types such as sea grass, sand ripple and hard-packed sand, etc. Target objects in SAS imagery often have varying characteristics and features due to changing environmental context. Therefore, methods that can identify the seabed environment can be used to assist in target classification and detection in an environmentally adaptive or context-dependent approach. In this paper, a possibilistic context identification approach is used to identify the seabed contexts. Alternative methods, such as crisp, fuzzy or probabilistic methods, would force one type of context on every sample in the imagery, ignoring the possibility that the test imagery may include an environmental context that has not yet appeared in the training process. The proposed possibilistic approach has an advantage in that it can both identify known contexts as well as identify when an unknown context has been encountered. Experiments are conducted on a collection of SAS imagery that display a variety of environmental features.

9454-56, Session 14

Dictionary learning for sparse sonar image representations

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

Frame methods, best basis methods, or dictionary learning methods provide a unique representation of a given dataset for applications like denoising or pattern recognition. Frame pursuit addresses the problem of finding optimal overcomplete bases to improve classification for pattern recognition applications. In this paper, the results of two optimization techniques applied to the optimal sparse dictionary problem are presented, K-SVD and genetic algorithm optimal frame pursuit. A multi-objective cost function is used to evaluate the goodness of the solutions over both sparsity and image classification. These techniques are applied over two sonar datasets one real aperture and one synthetic aperture. Results demonstrate the usefulness of dictionary learning and a correlation between dictionary properties and the performance of the dictionary to capture relevant discriminating information for pattern recognition.

9454-57, Session 15

Investigation of measureable parameters that correlate with automated target recognition performance in synthetic aperture sonar

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

There is a desire in the Mine Counter Measure community to develop a systematic method to predict and/or estimate the performance of Automated Target Recognition (ATR) algorithms that are detecting and classifying mine-like objects within sonar data. Ideally, parameters exist that can be measured directly from the sonar data that correlate with ATR performance. In this effort, two metrics were analyzed for their predictive potential using high frequency synthetic aperture sonar (SAS) images. The first parameter is a measure of contrast. It is essentially the variance in pixel intensity over a fixed partition of relatively small size. An analysis was performed to determine the optimum block size for this contrast calculation. These blocks were then overlapped in the horizontal and vertical direction over the entire image. The second parameter is the one-dimensional K-shape parameter. The K-distribution is commonly used to describe sonar backscatter return from range cells that contain a finite number of scatterers. An Ada-Boosted Decision Tree classifier was used to calculate the probability of classification (Pc) and false alarm rate (FAR) for several types of targets in SAS images from three different data sets. ROC curves as a function of the measured parameters were generated and the correlation between the measured parameters in the vicinity of each of the contacts and the ATR performance was investigated. The contrast and k-shape parameters were considered separately. Additionally, the contrast and k-shape parameter were associated with background texture types using previously labeled high frequency SAS images.

9454-58, Session 15

Unsupervised 3D scene understanding and prediction to enable adaptable approximate solutions to the art gallery problem and watchman route problem

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The art gallery problem (AGP) asks the question: “How can we place a small set of sensors to provide maximum coverage of an observed environment?” The watchman route problem (WRP) operates in conjunction with the AGP by asking the question “How do we create the shortest route between AGP-solving positions?” Providing approximate solutions to the AGP and WRP has been accomplished by using the previously-developed Sensor Placement Optimization via Queries (SPOQ) and the Photon-mapping-Informed active-Contour Route Designator (PICRD) algorithms. The objective of this work is to provide a means of assessing where to place both static and mobile sensors in order to approximately solve the AGP and

WRP, respectively, while adapting subsequent approximately optimal AGP/WRP-solutions in anticipation of future events. We can fulfill this objective by 1) extracting a 3D point cloud representation of the item of interest (IOI) to be surveiled in a video frame, 2) determine the highest-probability anticipated behavior by the IOI based upon training data and 3) incorporate the information gained from items 1 and 2 in order to obtain approximate solutions to the AGP and WRP using the respective SPOQ and PICRD algorithms. In this paper, we show how to accomplish the goals listed in items 1, 2 and 3 and thus fulfill our objective.

9454-59, Session 15

Polar format algorithm for cooperative radar engagement SAR imaging

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In the context of investigating cooperative radar engagement using synthetic aperture radar (SAR) mode, we examine the polar format algorithm (PFA) for image formation. The cooperative radar engagement technique is akin to bistatic SAR principle in which the transmitter and the receiver are on separate platforms, and is seen as a potential means of countering the vulnerability of conventional monostatic SAR to electronic countermeasures, particularly directional jamming and thereby avoiding physical attack of the imaging platform.

The work presented here investigates theoretical and mathematical formulation behind PFA for cooperative radar engagement and examples of simulated data for sea surface target image formation.

9454-60, Session 15

Automated area segmentation for ocean bottom surveys

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In practice, environmental information about an ocean bottom area to be searched using SONAR is often known a priori to some coarse level of resolution. The SONAR search sensor then typically has a different performance characterization function for each environmental classification. Large ocean bottom surveys using search SONAR can pose some difficulties when the environmental conditions vary significantly over the search area because search planning tools cannot adequately segment the area into sub-regions of homogeneous search sensor performance. Such segmentation is critically important to unmanned search vehicles; homogenous bottom segmentation will result in more accurate predictions of search performance and area coverage rate. The Naval Surface Warfare Center, Panama City Division has developed an automated area segmentation algorithm that subdivides the mission area under the constraint that the variation of the search sensor's performance within each sub-mission area cannot exceed a specified threshold, thereby creating sub-regions of homogeneous sensor performance. The algorithm also calculates a new, composite sensor performance function for each sub-mission area. The technique accounts for practical constraints such as enforcing a minimum sub-mission area size and requiring sub-mission areas to be rectangular. Segmentation occurs both across the rows and down the columns of the mission area. Ideally, mission planning should consider both segmentation directions and choose the one with the more favorable result. The Automated Area Segmentation Algorithm was tested using two a priori bottom segmentations: rectangular and triangular; and two search sensor configurations: a set of three bi-modal curves and a set of three uni-modal curves. For each of these four scenarios, the Automated Area Segmentation Algorithm automatically partitioned the mission area across rows and down columns to create regions with homogeneous sensor performance. The testing results indicated that the algorithm correctly segmented the rectangular a priori regions. For the triangular a priori segmentation, the algorithm created reasonable rectangular sub-areas.

Conference 9455: Chemical, Biological, Radiological, Nuclear, and Explosives (CBRNE) Sensing XVI

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9455-1, Session 1

Neutron spectroscopy using III-V semiconductor scintillators

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For the detection and identification of nuclear materials it is necessary that their radioactive-emission signatures be determined without ambiguity. That requires characterizing their gamma and neutron signatures. Currently, large numbers of portable devices are available for gamma spectroscopy and for the detection of thermal neutrons. However, field deployable devices suitable for fast neutron spectroscopy are lacking. Successful attempts to use CLYC, solid-state scintillator detectors via the 35Cl (n,p) reaction for fast neutron spectroscopy have been reported. However, their dynamic range is very limited due to the relatively low cross-section associated with the neutron-induced reaction. It is desirable to enhance this dynamic range from 300 keV to 4 MeV of neutron energy. Our goal is to investigate the feasibility of a direct band gap semiconductor n+InP as a new scintillator for fast neutron spectroscopy using proton recoil technique. Direct Band Gap Semiconductors have higher radiative efficiency and have the potential of higher photon yield, which are desirable features for a scintillator used for pulse height analysis. For our investigation InP will be implanted with H+ ions using proton beam from our Pelletron accelerator. In this paper we present our computational results.We have computed the expected depth profile of implanted hydrogen ions for (n,p) reaction. It is shown that, under ideal conditions, neutron irradiation of hydrogen implanted InP creates proton recoil scintillation with photon output being directly proportional to incoming neutron energy. It has been found that for the desirable dynamic range of neutron energy, loss to phonon creation in the lattice is negligible compare to energy used in electron excitation which results in the linear response in energy versus pulse height spectrum. Experimental work is in progress.

9455-2, Session 1

Subwavelength films for standoff radiation dosimetry

Kyle J. Alvine, Bruce E. Bernacki, Wendy D. Bennett, Pacific Northwest National Lab. (United States); Alan Schemer-Kohrn, Pacific Northwest National Lab (United States); Jonathan D. Suter, Pacific Northwest National Lab. (United States)

We present an optical subwavelength nanostructure architecture suitable for standoff radiation dosimetry with remote optical readout in the visible or infrared spectral regions. To achieve this, films of subwavelength structures are fabricated over several inches via the creation of a 2D array template of radiation sensitive polymeric nanoparticles, followed by magnetron sputtering of a metallic coating to form isolated hemispherical nanoscale metallic shells. The nano-shells are highly reflective at resonance in the visible or infrared depending on design. These structures and their behavior are based on the open ring resonator (ORR) architecture and have their analog in resonant LC circuits, which display a resonance wavelength that is inversely proportional to the square root of the product of the inductance and capacitance. Therefore, any modification of the nanostructure material properties due to radiation alters the inductive or capacitive behavior of the subwavelength features, which in turn changes their optical properties resulting in a shift in the optical resonance. This shift in resonance may be remotely actively using either laser illumination or passive hyperspectral or multispectral sensing with broadband illumination. These structures may be designed to be either anisotropic or isotropic, which can also offer polarization-sensitive interrogation. We present experimental measurements of the shift in the optical resonance of a subwavelength film after exposure to an absorbed dose of gamma radiation from 2 Mrad up to 62 Mrad demonstrating the effect. Interestingly the resonance shift is non-monotonic for this material system and possible radiation damage mechanisms to the nanoparticles are discussed.

9455-3, Session 1

Dehydration of uranyl nitrate hexahydrate to uranyl nitrate trihydrate under ambient conditions as observed via dynamic infrared reflectance spectroscopy

Timothy J. Johnson, Lucas E. Sweet, David E. Meier, Pacific Northwest National Lab. (United States); Edward J. Mausolf, Pacific Northwest National Lab. (United States) and Univ. of Nevada, Las Vegas (United States); Eunja Kim, Univ. of Nevada, Las Vegas (United States); Philippe F. Weck, Sandia National Labs. (United States); Edgar C. Buck, Bruce K. McNamara, Pacific Northwest National Lab. (United States)

Uranyl nitrate is a key species in the nuclear fuel cycle. However, it is known to exist in different states of hydration, including the hexahydrate [UO2(NO3)2(H2O)6] and the trihydrate [UO2(NO3)2(H2O)3] forms. Their relative stabilities depend on both water vapor pressure and temperature. In the late 1950s the different phases were studied by infrared transmission spectroscopy, but were limited both by instrumental resolution and by the ability to prepare the samples as transmission pellets without desiccating the sample. We report seminal measurements of time-resolved infrared spectroscopy using an integrating sphere that allow us to observe the transformation from the hexahydrate to the trihydrate simply by flowing a stream of dry nitrogen gas over the sample. Samples of known hydration state (the hexahydrate) were prepared and confirmed via known x-ray diffraction patterns. In reflectance mode the hexahydrate UO2(NO3)2(H2O)6 has a distinct uranyl asymmetric stretch band at 949.0 cm-1 that shifts to shorter wavelengths and broadens as the sample dehydrates and recrystallizes to the trihydrate, first as a shoulder growing in on the blue edge but ultimately results in a doublet band with reflectance peaks at 966 and 957 cm-1. The data are consistent with transformation from UNH to UNT since UNT has two non-equivalent UO22+ sites. The dehydration of UO2(NO3)2(H2O)6 to UO2(NO3)2(H2O)3 is both a structural and morphological change that has the lustrous lime green UO2(NO3)2(H2O)6 crystals changing to the dull greenish yellow of the trihydrate. The crystal structures and phase transformation were confirmed theoretically using density functional theory calculations and experimentally via optical microscopy methods. Both methods showed a transformation with two distinct sites for the uranyl cation in the trihydrate, as opposed to a single crystallographic site in the hexahydrate.

9455-4, Session 1

Effects of sample preparation on the infrared reflectance spectra of powders

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While reflectance spectroscopy is a useful tool in identifying molecular compounds, laboratory measurement of solid (particularly powder) samples often is confounded by sample preparation methods. For example, both the packing density and surface roughness can have an effect on the quantitative reflectance spectra of powdered samples. Recent efforts in our group have focused on developing standard methods for measuring reflectance spectra that accounts for sample preparation, as well as other factors such as particle size and provenance. In this work, the effect of preparation method on sample reflectivity was investigated by measuring the directional-hemispherical spectra of samples that were hand-packed as well as pressed into pellets using an integrating sphere attached to a Fourier transform infrared spectrometer. The results show that the methods used to prepare the sample have a substantial effect on the measured reflectance spectra, as do other factors such as particle size.

9455-5, Session 1

Use of CLYC spectrometer in counter-terrorism applications

Harry Ing, Bubble Technology Industries, Inc. (Canada)

A new crystal now known as CLYC (Cs_2LiYCl_6:Ce) has been under development for over 15 years(1). It was primarily of interest for radiation detection applications because of its good energy resolution for gamma rays (<4% for 662 keV) and its capability for detection of thermal neutrons. The pulse shapes of the signals from the two radiations are different which allows them to be separated electronically, permitting simultaneous detection of gamma rays and neutrons. The crystal is now commercially available. Early investigations of the neutron response by the current authors (2) revealed that CLYC also responds to fast neutrons. In fact, the good energy resolution of the response under monoenergetic neutron irradiations showed that CLYC was an excellent high-energy neutron spectrometer. This discovery has great impact on the field of neutron spectroscopy, which has numerous, although often specialized, applications. This presentation focuses on applications in counter-terrorism scenarios where neutrons may be involved. The relative importance of the fast neutron response of CLYC, compared to the thermal and gamma-ray response, under such scenarios will be discussed.

(1) C.M. Combes, P. Dorenbos, C.W.E. van Eijk, K.W. Krämer, H.U. Güdel, J. Lumin. 82 (1999) 299-305

(2) M.B. Smith, T. Achtzehn, H.R. Andrews, E.T.H. Clifford, H. Ing, V.D. Kovaltchouk, IEEE Trans. Nucl. Sci 60(2) (2013) 855-859

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9455-10, Session 3

Quartz crystal microbalance biosensor for rapid detection of aerosolized microorganisms

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Biological warfare agents (BWAs) represent the current menace of the asymmetric war. The early detection of BWAs, especially in the form of bioaerosol, is a challenging task for governments all around the world. Label-free quartz crystal microbalance (QCM) based immunosensor was developed and tested for rapid detection of BWA surrogates (E. coli strains BL21, DH5 alpha and K-12) in the form of bioaerosol. Two immobilization strategies for the attachment of antibody were tested; the gold sensor surface was activated by cysteamine and then antibody was covalently linked either using glutaraldehyde, or the reduced antibodies were attached via Sulfo-SMCC. A portable bioaerosol chamber was constructed and used for safe manipulation with aerosolized microorganisms. The dissemination was done using a piezoelectric humidifier, distribution of bioaerosol inside the chamber was ensured using three 12-cm fans. The whole system was controlled remotely using LAN network. The disseminated microbial cells were collected and preconcentrated using the wetted-wall cyclone SASS 2300, the analysis was done using the on-line linked QCM immunosensor. Limit of detection 1.45?10^4 CFU L-1 of air was achieved with analysis time 16 min, the whole experiment including dissemination and sensor surface regeneration took 40 min. In case of blank (disseminated sterile buffer), no signal change was observed. Reference measurements were done using particle counter Met One 3400 and by cultivation method on agar plates. The sensor proved to be applicable for rapid screening of model microorganism in air and with appropriate antibody, it can be used also for detection of real aerosolized BWAs.

9455-11, Session 3

Standoff detection and classification procedure for bioorganic compounds by hyperspectral laser-induced fluorescence

Thomas Fischbach, Frank Duschek, Anita Hausmann, Carsten Pargmann, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); Valeri Alekseyev, Larisa Porovkina, Innokenti Sobolev, Sergey Babichenko, Laser Diagnostic Instruments AS (Estonia); Jürgen Handke, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

The high and still increasing number of attacks by hazardous bioorganic materials makes enormous demands on their detection. A very high detection sensitivity and selectivity are essential, as well as a rapid identification with low false alarm rates. A single method can hardly achieve this. Point sensors can collect and identify materials, but positioning at appropriate locations is time consuming and involves several risks. Laser based standoff detection, however, can immediately provide information on propagation and compound type of a released hazardous material. The coupling of both methods may be a promising solution to optimize the acquisition and detection of hazardous substances.

At DLR Lampoldshausen, bioorganic substances are measured applying hyperspectral laser induced fluorescence (LIF) technique in order to subsequently classify them. In this work, a procedure is presented, which utilizes time-dependent spectral data and predicts the presence of hazardous substances by statistical data analysis. For that purpose, measurements are carried out on a free transmission range at a standoff distance of 22 m. The fluorescence excitation wavelengths are 280 and 355 nm in alternating mode. A gated ICCD spectrometer system records spectral and time-dependent fluorescence data, which are processed and fed automatically into the classifier. Attention is drawn to physical states, concentrations, and to the photodecomposition of the samples assisted by absorption spectroscopy before and after each LIF measurement. This has a strong impact on the measurement procedure and, especially, on the training of the classifier.

9455-12, Session 3

Bioaerosol detection and classification using dual excitation wavelength laser-induced fluorescence

Per Jonsson, Pär Wästerby, Per-Åke Gradmark, Julia Hedborg, Anders Larsson, Lars Landström, FOI (Sweden)

We present results obtained by a detection system designed to measure laser-induced fluorescence from individual aerosol particles using dual excitation wavelengths. The aerosol is sampled from ambient air and via a 1 mm diameter nozzle, surrounded by a sheath air flow, confined into a particle beam. A continuous wave blue laser at 404 nm is focused on the aerosol beam and two photomultiplier tubes monitor the presence of individual particles by simultaneous measuring the scattered light and any induced fluorescence. When a particle is present in the detection volume, a laser pulse is triggered from an ultraviolet laser at 263 nm and the corresponding fluorescence spectrum is acquired with a spectrometer based on a diffraction grating and a 32 channel photomultiplier tube array with single-photon sensitivity. The spectrometer measures the fluorescence spectra in the wavelength region from 250 to 800 nm. In the present report, data were measured on different simulants of biological warfare agents (cultivated in different growth media) and different interference aerosol particles, e.g. pollen. In the analysis of the experimental data, i.e., the time-resolved scattered and fluorescence signals from 404 nm c.w. light excitation and the fluorescence spectra obtained by a pulsed 263 nm laser source, we use different multivariate data analysis methods to classify each individual aerosol particle.

9455-13, Session 3

Analysis of protective antigen peptide binding motifs using bacterial display technology

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In today's fast-paced world, a new biological threat could emerge at any time, necessitating a prompt, reliable, inexpensive detection reagent in each case. Combined with magnetic-activated cell sorting (MACS), bacterial display technology makes this possible, isolating selective, high affinity peptide reagents in days to weeks. We will discuss current methods available for bacterial display sorting, and investigate the commercially-available, semi-automated autoMACS® Pro Separator as a platform to improve reproducibility of biopanning by bacterial display. Current protocols for this platform include biopanning by yeast surface display, but focus on eukaryotic cells. In parallel with manual magnetic sorting, two autoMACS® programs designed for low frequency of target cells were used to isolate candidate peptides to protective antigen (PA) of Bacillus anthracis. After four rounds of sorting, relative binding performance to PA was assessed and compared for each sorting round and individual candidates using Fluorescence-Actived Cell Sorting. By round 3, it was evident that the bacterial display library had been enriched by autoMACS sorting, but not manual sorting. Assessing individual candidates, biopanning by autoMACS yielded higher affinity, more selective peptide candidates than biopanning by manual MACS. In addition, bioinformatics analysis of the autoMACS candidates yielded the same consensus previously obtained while screening for PA peptide candidates using a competing semi-automated technology, as well as other binding motifs which were studied for their role in relative binding performance.

9455-14, Session 3

Multisense chip: continuously working air monitoring system: An integrated system for the detection of airborne biological pathogens on molecular and immunological level

Claudia Gärtner, Holger Becker, Nadine Hlawatsch, Richard Klemm, Sebastian Schattschneider, Christian Moche, microfluidic ChipShop GmbH (Germany)

Lab-on-a-chip systems are very promising approach for a decentralized continuous pathogen monitoring. The overall presented system consisting of a microtiter plate sized consumable and the respective instrument allows for the detection of airborne biological pathogen. The target pathogens to be detected are Yersinia pestis, Francisella tularensis, Burkholderia mallei, Burkholderia pseudomallei, Brucella melitensis, Brucella abortis, Coxiella burnetti, and Bacillus anthracis. Important to stress that the technical platform can be easily expanded to further pathogens.

In this paper the development of a fully integrated system for the 8-plex detection of bacterial pathogens will be presented. Two exceptional features are combined in this device: The overall system allows for the permanent sampling and analysis of airborne biological pathogens and combines the detection of the respective bacteria on molecular and immunological level.

Permanent monitoring of airborne bacteria is an essential tool to ensure clean and safe environment be it in a hospital surrounding, metro stations, airports or for big events like football games or international sport events.

The presented system combines the sampling of airborne particles through an air sampling system based on Coriolis forces. The enriched particles are directly transferred in a liquid phase. This first enrichment step is followed by a volume reduction of the liquid phase for air sampling achieved directly on the lab-on-a-chip device. The concentrated sample undergoes a cell lysis and is afterwards splitted in two fractions, one sample fraction following the immunological path where an ELISA is carried out on chip. Detection is carried out by colorimetric measurement. The molecular assay uses the lysed sample material to undergo a PCR, whereas a special kind of PCR is use: A continuous flow PCR approach where the sample is guided through a meander channel embedded on chip over fixed temperature zones in the instrument. This speciality leads to extremely fast PCR and low power consumption due to the lack of heating up and cooling down the instrument since only the sample plug undergoes the thermal cycleing, furthermore the sample can be injected permanently in a continuous flow mode. Finally a fluorescence detection is carried out.

Besides the implementation of the overall assay on chip two main achievements were made: Firstly, the surface of the immunoassay despite being flushed permanently can be used over a longer period for continuous monitoring of negative results. For the case of positive results the system will trigger an alert and the chip will be disposed. Secondly, a PCR protocol in respect to temperature and cycle timing was developed allowing to run all eight target PCR with the same protocol.

The overall system consisting of chip and instrument and the biological procedures embedded on chip will be presented.

9455-15, Session 4

Hyperspectral image analysis for detection of explosive substances using IR laser standoff spectroscopy

Jan-Philip Jarvis, Frank Fuchs, Stefan Hugger, Quankui K. Yang, Ralf Ostendorf, Christian Schilling, Wolfgang Bronner, Rachid Driad, Rolf Aidam, Joachim Wagner, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany)

In this work we present a hyperspectral image sensor based on MIR-laser backscattering spectroscopy for contactless detection of explosive substance traces. The spectroscopy system comprises two tunable Quantum Cascade Laser sources covering a total tuning range of 300cm-1 from 7.7µm to 10µm. A high performance Mercury-Cadmium-Telluride infrared camera is used to collect the diffusely backscattered light. The resulting measurement data forms a hyperspectral image, where each pixel vector contains the backscattering spectrum of a specific location in the scene. The hyperspectral image data is analyzed for traces of target substances using a state of the art target detection algorithm (the Adaptive Matched Subspace Detector) together with an appropriate background extraction method (the Adaptive Target Generation Process). In this work we give a detailed description of the hyperspectral image sensor with a focus on the mentioned data analysis algorithms together with various target detection performance evaluations.

In imaging applications it can often be difficult – if not impossible – to obtain valid ground truth data, even under laboratory conditions. Therefore, we employ artificial hyperspectral image data using the well-known Linear Mixture Model (LMM) as data generation model for system evaluation. This approach allows us to accurately inspect the impact of various noise sources commonly observed in real world measurement data on target detection performance by analyzing the resulting Receiver Operating Characteristics (ROCs). The latter, can also be employed to evaluate the impact of the spectral characteristic of various substances on detection sensitivity. We show, that the selected measurement wavelength range is of crucial importance by comparing the detection performance of different explosive substances including PETN, TNT, RDX and Ammonium Nitrate.

Finally, we present measurement results that demonstrate the system's applicability under real-world conditions.

9455-17, Session 4

Bioinspired digital signal processing for fast radionuclide mixture identification

Mathieu Thevenin, Olivier Bichler, Cheick Thiam, Christophe Bobin, Commissariat à l'Énergie Atomique (France)

Countries are trying to equip their public transportation infrastructure with radiation portals and detectors to detect radiological threat. Current works usually focus on neutron detection, which could be useless in the case of dirty bomb that would not use fissile material. Other approaches, such as gamma dose rate variation monitoring is a good indication of the presence of radionuclide. However, some legitimate products emit large quantities of natural gamma rays; environment also emits gamma rays naturally. They can lead to false detections. Moreover, such radio-activity could be used to hide a threat such as material to make a dirty bomb. Consequently, radionuclide identification is a requirement and is traditionally performed by gamma spectroscopy using unique spectral signature of each radionuclide. These approaches require high-resolution detectors, sufficient integration time to get enough statistics and large computing capacities for data analysis. High-resolution detectors are fragile and costly, making them bad candidates for large scale homeland security applications. Plastic scintillator and NaI detectors fit with such applications but their resolution makes identification difficult, especially radionuclides mixes. This paper proposes an original signal processing strategy based on artificial spiking neural networks to enable fast radionuclide identification at low count rate and for mixtures. It presents results obtained for different challenging mixtures of radionuclides using a NaI scintillator. Results show that a correct identification is performed with less than hundred counts and no false identification is reported, enabling quick identification of a moving threat in a public transportation. Further work will focus on using plastic scintillators.

9455-18, Session 4

Single-wavelength lidar retrieval algorithm of particulate matter concentration using CELiS (compact eyesafe lidar system) a 1.5 µm elastic lidar system

Alan W. Bird, Kori D. Moore, Michael D. Wojcik, Robert Lemon, Utah State Univ. (United States)

CELiS (Compact Eyesafe Lidar System) is an elastic backscatter light detection and ranging (Lidar) system developed for monitoring air quality environmental compliance regarding particulate matter (PM) generated from off-road use of wheeled and tracked vehicles as part of the SERDP (Strategic Environmental Research and Development Program) Measurement and Modeling of Fugitive Dust Emission from Off-Road DoD Activities program.

CELiS is small, lightweight and easily transportable for quick setup and measurement of PM concentration and emissions. CELiS operates in a biaxial configuration at the 1.5µm eyesafe wavelength with a working range of better than 6km and range resolution of 5m.

In this paper we describe an algorithm that allows for semi-quantitative PM determination under a set of guiding assumptions using a single wavelength Lidar. Meteorological and particle measurements are used to estimate the total extinction σ and β backscatter at a calibration point located at the end range of the Lidar. These σ and β values are used in conjunction with the Klett inversion to estimate σ and β over the Lidar beam path. A relationship between σ, β and PM mass concentrations at calibration points is developed, which then allows the β and σ values derived to be converted to PM at each Lidar bin over the Lidar beam path.

CELiS can be used to investigate PM concentrations and emissions over a large volume, a task that is very difficult to accomplish with typical PM sensors.

9455-19, Session 4

Maximum discrimination approach for classification of nearly identical signatures

Darren K. Emge, U.S. Army Edgewood Chemical Biological Ctr. (United States); Steven Kay, The Univ. of Rhode Island (United States)

We present a method for classifying nearly identical spectral signatures utilizing maximum discrimination bands. The use maximum discrimination bands, can overcome the performance degradation that can be encountered when attempting to classify highly similar spectral signatures. The observed reduction in performance results from the inclusion of non discriminatory bands when utilizing the full spectral signatures. To overcome this problem we present a method that utilizes a Kullback-Leibler distance framework, based upon the assumption of equal prior probabilities, to identify the maximum discrimination bands. The use of maximum discrimination bands will be shown to enhance the performance when trying to distinguish between chemicals with highly similar spectra. Through simulation, we will show the improvement in performance gained using the proposed method. As an example of a real world application of the presented method, a comparison of the classification of 2,4-dinitrotoluene and 2,6-dinitrotoluene will be presented. The maximum discrimination approach can be utilized in a two step classification approach in which highly similar chemicals are first classified as a group. This can be followed by the use of maximum discrimination bands to correctly classify chemicals with highly similar spectra.

9455-20, Session 4

Non-specific sensor arrays for chemical detection

Kevin J. Johnson, U.S. Naval Research Lab. (United States); Christian P. Minor, Nova Research, Inc. (United States)

Non-specific chemical sensor arrays have been the subject of considerable research efforts over the past thirty years with the idea that, by analogy to vertebrate olfaction, they are potentially capable of rendering complex chemical assessments with relatively modest logistical footprints. However, the actual implementation of such devices in challenging "real world" scenarios has arguably continued to fall short of these expectations. This work examines the inherent limitations of such devices for complex chemical sensing scenarios, placing them on a continuum between simple univariate sensors and complex multivariate analytical instrumentation and analyzing their utility in general-purpose chemical detection and accurate chemical sensing in the presence of unknown "unknowns." Results with simulated and acquired data sets are presented with discussion of the development and implementation of chemical sensor arrays suitable for qualitative or quantitative scenarios.

9455-21, Session 4

Removal of nonresonant background in MCARS spectra using Fourier filtering

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

Multiplex coherent anti-Stokes Raman spectroscopy (MCARS) has been used to create a complete Raman spectrum of a material of interest in milliseconds. However, these MCARS spectra often embedded in a nonresonant background that reduces the ability to use those spectra to positively identify the material of interest. There are a number of techniques that are used experimentally to reduce the nonresonant background when taking the MCARS spectrum. However, there are situations where these experimental nonresonant background reduction techniques may result in a loss of the desired MCARS signal. In an effort to maintain the signal strength of the MCARS spectrum, analytical methods of background removal are employed. There are a number of analytical techniques for nonresonant background removal from MCARS signals. However, many of them either make blanket assumptions about the nonresonant background that sacrifice accuracy of the technique or require knowledge of the material of interest before removing the nonresonant background. We will be reporting on an analytical method to remove the nonresonant background that utilizes a combination of the maximum entropy method to reproduce the spectrum as well as complex spectral filtering to remove the nonresonant background and accurately determine the CARS spectrum interest without prior knowledge of the material of interest.

9455-22, Session 4

Trace explosives detection using photo-thermal infrared imaging spectroscopy (PT-IRIS): theory, modeling, and detection algorithms

Robert Furstenberg, Christopher A. Kendziora, Michael R. Papantonakis, Viet Nguyen, Jeff M. Byers, R. Andrew McGill, U.S. Naval Research Lab. (United States)

We are developing a technology for stand-off detection based on photo-thermal infrared (IR) imaging spectroscopy (PT-IRIS). In this approach, one or more IR quantum cascade lasers are tuned to strong absorption bands in the analytes and directed at the sample while an IR focal plane array is used to image the subsequent thermal emissions. In this paper we present recent advances in PT-IRIS hardware design, experiments, and the theory and numerical modeling of photo-thermal imaging and spectroscopy of particulates on flat substrates. We compare the theoretical models with experimental data taken on our mobile cart-based PT-IRIS system. Synthetic data of the photo-thermal response was calculated for a wide range of analytes, substrates, particle sizes and analyte mass loadings using their known thermo-physical and optical properties. These synthetic data sets can now be generated quickly and were used to accelerate the development of detection algorithms. The performance of detection algorithms will also be discussed.

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.

9455-23, Session 5

Intracavity optical parametric oscillators based upon orientation-patterned GaAs (OPGaAs): development toward a flexible deep-infrared active hyperspectral imaging system *(Invited Paper)*

David M. Stothard, Daniel J. Kane, Fraunhofer Ctr. for Applied Photonics (United Kingdom); Peter G. Schunemann, BAE Systems (United States); Malcolm H. Dunn, Malcolm H. Dunn, Univ. of St. Andrews (United Kingdom)

Spectroscopic imaging is an ideal means for the rapid detection of toxic, explosive or otherwise hazardous and contraband substances. Many passive and active hyperspectral imaging systems have been developed to this end, and those based upon active illumination with a narrow-band, widely tunable laser sources have shown particular promise for species discrimination and identification due to the exception spectral brightness of the laser illumination sources upon which they depend (and whose linewidth defines the spectral resolution of the system). Optical parametric oscillators (OPOs) offer an ideal route to the generation of widely tunable, narrow-band radiation in the waveband of interest and to date such systems have typically been predicated upon the nonlinear material periodically-poled lithium niobate (PPLN). Whilst these devices offer low threshold, potentially compact designs (particularly when implemented in the intracavity geometry), the transmission properties of PPLN limit their use to the mid-infrared spectral band (~1.5-4.5μm). This is problematic as it is at longer wavelengths, (the so-called ~6-10μm spectral fingerprint region) that many molecules and substances of interest exhibit their peak rotational and vibrational optical absorption. OPGaAs is becoming established as an excellent material for deep-infrared radiation generation through parametric down-conversion and is poised to become the "PPLN" of deep infrared OPOs. Recent developments have led to improvements in its linear transmission at the pumping wavelength around 2μm, and this enables it to be placed within the cavity of the parent pump laser where it can access its high circulating field – substantially reducing the external (diode) pumping power required to reach threshold. In this talk I will present recent work towards developing such an intracavity OPO based upon both established and emergent parent pump laser technology, and discuss its potential in the context of back-scatter absorption imaging (BAGI) for the rapid spectroscopic detection and imaging of hazardous substances.

9455-24, Session 5

New plasmonic materials and fabrication tools for near- and mid-infrared sensing *(Invited Paper)*

Otto L. Muskens, Yudong Wang, Leo-Jay Black, Cornelis Hendrik de Groot, Univ. of Southampton (United Kingdom); Arnaud Arbouet, Ctr. d'Elaboration de Matériaux et d'Etudes Structurales (France)

Plasmonics, the manipulation of electromagnetic fields on nanometer length scales using small metal structures, has many applications in sensing. The enhancement of electromagnetic fields around metallic nanostructures is of interest for enhancing the interaction of light with molecules. Precise rational design of the plasmonic structures is of importance to optimize this interaction strength. In addition, recent years have seen a development toward new materials for plasmonics, with applications in near- and mid-infrared. Here, I will give an overview of new directions in nanofabrication of plasmonic structures aimed toward combined Raman and infrared gas sensing for defense applications, including new helium-ion beam milling tools [1], oxide and nitride plasmonics [2], and their use in plasmon-enhanced spectroscopy, spectral and polarization sensitive filters and metasurfaces [3].

[1] Y. Wang, M. Abb, S. A. Boden, J. Aizpurua, C. H. de Groot, O. L. Muskens, Ultrafast nonlinear control of progressively loaded, single plasmonic nanoantennas fabricated using helium ion milling,

Nano Lett. 13, 5647-5653 (2013)

[2] L.-J. Black, Y. Wang, C. H. de Groot, A. Arbouet, O. L. Muskens, Optimal Polarization Conversion in Coupled Dimer Plasmonic Nanoantennas for Metasurfaces, ACS Nano 8(6), 6390–6399 (2014)

[3] M. Abb, Y. Wang, N. Papasimakis, C. H. de Groot, O. L. Muskens, Surface-Enhanced Infrared Spectroscopy Using Metal Oxide Plasmonic Antenna Arrays, Nano Lett. 14 (1), 346–352 (2014)

9455-25, Session 5

Detection of chemical clouds using widely tunable quantum cascade lasers

Anish K. Goyal, Petros Kotidis, Erik R. Deutsch, Ninghui Zhu, Mark Norman, Jim Ye, Kostas Zafiriou, Alexander Mazurenko, Block Engineering, LLC (United States)

Widely tunable quantum cascade lasers (QCLs) spanning the long-wave infrared (LWIR) atmospheric transmission window and an HgCdTe detector were incorporated transceiver for line-of-sight atmospheric sensing for the detection of chemical clouds. The system is compact having a 50-mm-diameter transmit/receive aperture. When used in combination with a 50-mm-diameter hollow retroreflector, the system has been used to perform atmospheric sensing over round-trip path lengths of >500 meters. The system has been operated continuously for several days and demonstrated the capability to detect and identify a wide variety of gases with detection sensitivities in the parts-per-billion range when averaged over the path length. Two rapidly tunable QCLs spanned the wavelength range of 7.7 to 13 microns within a fraction of a second. Transmission measurements between the transceiver and retoreflector were made with a spectral resolution of 2 cm-1 as a function of distance to the retroreflector with a maximum round-trip distance of >500 meters. Freon 132 and other gases were sprayed into the beam path and the concentration-length product (CLP) was measured as a function of time. The system exhibited a noise-equivalent concentration (NEC) of 3 ppb for Freon 132 for a round-trip path of 310 meters. Algorithms based on correlation methods were used to both identify the gas and to determine its CLP as a function of time. This presentation will detail the system design and detection algorithm. Also discussed will be the relative advantages of QCL-based open-path spectrometers with those based on Fourier-transform infrared (FTIR) spectrometers for the monitoring of atmospheric gases.

9455-26, Session 5

Detecting liquid contamination on surfaces using hyperspectral imaging data

Russell E. Warren, EO-Stat, Inc. (United States); David B. Cohn, DBC Technology Corp. (United States); Marc-André Gagnon, Vincent Farley, Telops (Canada)

Over the past two years we have developed a new approach for detecting and identifying the presence of liquid chemical contamination on surfaces using hyperspectral imaging data. This work requires an algorithm for unmixing the data to separate the liquid contamination component of the data from all other possible spectral effects, such as the illumination and reflectance spectra of the pure background. The contamination components from S and P polarized reflectance data are then used to estimate the complex refractive index. We retain the index estimates within spectral windows chosen for each of a set of candidate contaminant materials based on their optical extinction. Spectral estimates within those windows are characteristic of the liquid material, and can be passed on to an algorithm for chemical detection and identification. The resulting algorithm is insensitive to the composition of the surface material, and requires no prior measurements of the uncontaminated surface. In a series of field tests, data from the Telops Hyper-Cam sensor were used to develop and validate our approach. We discuss our hyperspectral unmixing and index estimation approaches, and show results from tests conducted at the Telops facility in Quebec under a contract with the U.S. Army Edgewood Chemical Biological Center.

9455-27, Session 5

The development of a wide-field, high-resolution UV Raman hyperspectral imager

Nathaniel R. Gomer, Matthew P. Nelson, ChemImage Corp. (United States); Stanley M. Angel, Univ. of South Carolina (United States)

Raman spectroscopy is a valuable tool for the investigation and analysis of explosive and biological analytes because it provides a unique molecular fingerprint that allows for unambiguous target identification. Raman can be advantageous when utilized with deep UV excitation, but typical deep UV Raman systems have numerous limitations that hinder their performance and make their potential integration onto a field portable platform difficult. These systems typically offer very low throughput, are physically large and heavy, and can only probe an area the size of a tightly focused laser, severely diminishing the ability of the system to investigate large areas efficiently. The majority of these limitations are directly related to a system's spectrometer, which is typically dispersive grating based and requires a very narrow slit width and long focal length optics to achieve high spectral resolution.

To address these shortcomings, ChemImage Sensor Systems (CISS), teaming with the University of South Carolina, are developing an innovative wide-field Raman hyperspectral imaging system capable of providing wide-area, high resolution measurements with greatly increased throughput in a small form factor would revolutionize the way Raman is conducted and applied. The innovation couples a spatial heterodyne spectrometer (SHS), a novel slit-less spectrometer that operates similar to the Michelson interferometer, with a fiber array spectral translator (FAST) fiber array, a two-dimensional imaging fiber for hyperspectral imagery, to create a novel wide-field, high throughput Raman hyperspectral imager capable of yielding very high spectral resolution in a small form factor. This paper will focus on the need for an innovative UV Raman system, provide an overview of spatial heterodyne Raman spectroscopy, and discuss the development of the system.

9455-28, Session 5

Advanced shortwave infrared and Raman hyperspectral sensors for homeland security and law enforcement operations

Matthew P. Nelson, Chuck Gardner, Nathaniel R. Gomer, ChemImage Corp. (United States)

Proliferation of chemical and explosive threats continues to be an escalating danger to civilian and military personnel. Conventional means of detecting and identifying hazardous materials often require the use of reagents and/or physical sampling, which is a time-consuming, costly and often dangerous process. Stand-off detection allows the operator to detect threat residues from a safer distance minimizing danger to people and equipment. Current fielded technologies for standoff detection of chemical and explosive threats are challenged by low area search rates, poor targeting efficiency, lack of sensitivity and specificity or use of costly and potentially unsafe equipment such as lasers. A demand exists for stand-off systems that are fast, safe, reliable and user-friendly.

To address this need, ChemImage Sensor Systems (CISS) has developed reagent-less, non-contact, non-destructive sensors for the real-time detection of hazardous materials based on widefield shortwave infrared (SWIR) and Raman hyperspectral imaging (HSI). Hyperspectral imaging enables automated target detection displayed in the form of image making result analysis intuitive and user-friendly.

Application of the CISS' SWIR-HSI and Raman sensing technologies to Homeland Security and Law Enforcement for standoff detection of homemade explosives and illicit drugs and their precursors in vehicle and personnel checkpoints will be discussed. Sensing technologies will include a portable, robot-mounted and standalone variants of the technology. Test data will be presented that support the use of SWIR and Raman HSI for explosive and drug screening at checkpoints as well as screening for explosives and drugs at suspected clandestine manufacturing facilities.

9455-29, Session 6

Characterization of inkjet-printed explosive materials

Mikella E. Farrell, Ellen L. Holthoff, Logan S. Marcus, Paul M. Pellegrino, U.S. Army Research Lab. (United States)

The requirement to detect hazardous materials at both point and standoff distances has led to the development of laser-based hazard detection systems with immediate application for the security and safety of the US military, national security agencies, and environmental response teams. In particular, common explosive and improvised explosive device (IED) materials have motivated research efforts toward detecting trace (<100 μg/cm2) and bulk (>100 μg/cm2) quantities of these threats on multiple surfaces. Test coupons must demonstrate realistic concentrations, mimic real life particle sizes, and be fabricated on a host of substrate materials in order to evaluate the ability of these systems to accurately detect and identify hazard materials.

At the Army Research Laboratory (ARL) we have developed a standardized sample preparation method for the evaluation of systems using test coupons with known concentrations of target material for the evaluation of the hazard detection systems. ARL test coupons are fabricated using an inkjet printing system. We will discuss the printing and characterization of test coupons for common explosive materials, like cyclotrimethylenetrinitramine (RDX), pentaerythritol tetranitrate (PETN), ammonium nitrate (AN) and urea. The explosives are printed onto substrates that mimic real world test conditions. Painted car panels, bare steel, and plastic substrates with the deposited explosives are characterized using Raman, scanning electron microscope (SEM) imaging, and profilometry measurements. These measurements have increased the understanding of how the materials set-up on substrates and our ability to better design standardized sample coupon creation protocols for comprehensive evaluation of hazard detection systems.

9455-30, Session 6

Single-shot stand-off detection of explosives precursors using UV coded aperture Raman spectroscopy

Mattias Svanqvist, Markus Nordberg, Henric Östmark, Swedish Defence Research Agency (Sweden)

Multiplexed spectroscopy using coded apertures (CA) can under certain conditions give a large increase in light collection compared to standard slit based configurations[1]. This can in turn, for example, be used to reduce measurement times, increase measurement distances, or increase sensitivity in stand-off Raman systems[2] designed to detect threat substances like explosives or other hazardous chemicals.

Measurements were done using the second harmonic of an Nd:YAG laser (Ekspla NL300) giving 6 ns pulses with 100mJ at 355 nm with a repetition rate of 10 Hz. The laser pulses illuminated bulk samples of ammonium nitrate (AN) and AN mixed with fuel oil (ANFO) positioned outside the laboratory at a distance of 10 meters. An 8 inch telescope (Celestron C91024-XLT) was used to collect the Raman scattered light emitted from the samples and additional beam shaping optics were used to optimize the beam before it entered the spectrometer.

The spectrometer used was a Spex 500M spectrometer, modified to allow for exchanging the slit for a coded aperture mask. The CA masks (produced by Applied Image Inc.) consists of a chrome oxide masking film on UV grade fused silica, AR coated for 266 nm, with a doubled Haddamard matrix pattern. The CA used in these experiments had 64x128 pixels with a size of 100 μm each, resulting in a total area of 12.8x6.4 mm^2. One mask pixel was imaged over 8 pixels on the ICCD camera (Andor USB iStar).

The detector images were demultiplexed and the resulting spectra were compared to measurements done using the same hardware with the original slit configuration (using a slit width of 100 μm, giving the same spectral resolution). The signal-to-noise ratio was found to be about an order of magnitude better in the mask configuration compared to using the slit.

[1] S.T. McCain et al, Applied Spectroscopy 60(6), 2006

[2] S. Wallin et al, Proc. of SPIE 8358(83580P), 2012

9455-32, Session 6

Advances in sublimation studies for particles of explosives

Robert Furstenberg, Tara Abrishami, Michael R. Papantonakis, Christopher A. Kendziora, David R. Mott, 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 crushing and depositions on a surface within a fingerprint. These particles provide an evidentiary trail for detection and forensic applications. The longevity or stability of explosives particles on a substrate is a function of particle geometry, substrate geometry, temperature, airflow, areal coverage, relative humidity, condensation, inclusion chemicals, exposed light and, in some instances, the substrate material type. In this work we deposit particles of explosives on smooth glass substrates by sieving, inkjetting or pipetting, and monitor their sublimation by photo/video-microscopy in a custom-made sublimation cell with controlled airflow, humidity and temperature. Analysis of 2D micrograph images is used to compute and track the size of each individual particle in a large particle ensemble as functions of time and experimental test conditions. 3D particle imaging, GCMS or UV-visible spectrophotometry are used to provide supporting confirmation to 2D image analysis. In this paper, we expand the set of test conditions including variable airflow rates and particle areal coverage (fingerprint representative values) at fixed humidity and temperature. We find that particles loaded at relatively low areal densities show essentially constant radial sublimation velocities (RSV) for different particle sizes, whereas higher loadings are found to significantly affect RSV values through micro-climate effects which form between particles. In connection to these results we expand the known sublimation models to include the effects of neighboring particle proximity at different flow rates.

9455-33, Session 7

Experimental examination of ultraviolet Raman cross sections of chemical warfare agent simulants

Fredrik Kullander, Lars Landström, Hampus Lundén, Pär Wästerby, Swedish Defence Research Agency (Sweden)

Laser induced Raman scattering from the commonly used chemical warfare agent simulants dimethylsolfoxide, tributhylphosphate, phosponoacetate was measured at excitation wavelengths ranging from 210 to 410 nm using a pulsed laser based spectrometer system with a probing distance of 1.4 m (and with an image size on the target of less than 1mm). Droplets of the substances were deposited on a silicon wafer to reduce the background level. For the purpose of comparison with well explored reference liquids the Raman scattering from simulants was additionally measured in the form of an extended liquid surface layer on top of a silicon wafer. This way of measuring enabled direct comparison to the Raman scattering strength from cyclohexane and acetonitrile. The reference Raman spectra were used to validate the signal strength of the simulants and calibrate the spectrometer. Measured UV absorbance functions were used to calculate Raman cross sections. The Raman signal strength from the simulants was then compared to that from chemical warfare agent droplets deposited in the same way.

9455-34, Session 7

Photoacoustic chemical sensing: layered systems and excitation source analysis

Logan S. Marcus, Ellen L. Holthoff, Paul M. Pellegrino, U.S. Army Research Lab. (United States)

Photoacoustic spectroscopy (PAS) is a versatile tool that is well suited for the ranged interrogation of layered samples. We have previously demonstrated standoff photoacoustic (PA) chemical detection of condensed phase samples at one meter distance using an interferometric sensing platform. Current research investigates layered solid samples constructed from a thin layer of energetic material deposited on a substrate. The PA signal from the system, as measured by the interferometer, changes based on the differing optical and mechanical properties of the substrate. This signal variance must be understood in order to develop a sensor capable of detecting trace quantities of hazardous materials independent of the surface. Optical absorption and modal excitation are the two biggest sources of PA signal generated in the sample/substrate system. Finally, the mode of operation of the excitation source is investigated. Most PA sensing paradigms use a quantum cascade laser (QCL) operating in either pulsed or modulated CW mode. We will discuss photoacoustic signal generation with respect to these different operating modes.

9455-35, Session 7

Cooperative use of standoff and UAV sensors for CBRNE detection

William J. Marinelli, Thomas Schmit, Julia Rentz Dupuis, David Manegold, Physical Sciences Inc. (United States); Manal Beshay, Marvin Lav, Intelligent Optical Systems, Inc. (United States)

The concurrent use of standoff and compact UAV sensors for the detection of chemical and radiological threats will be discussed in the context of a series of chemical release measurements as well as radiological source searches. The measurement utilized the InstantEye soldier UAV. The quad-copter UAV was equipped with either a colorimetric sensor for the detection of ammonia or a scintillator sensor for the detection of gamma-emitting radiological threats.

A range of standoff detection technologies were employed to provide initial cueing and flight guidance to the UAV. The AIRIS hyperspectral imaging sensor was used to provide initial identification and vector to potential chemical threats while DNDO's imaging Standoff Radiation Detection System (SORDS) was used to provide initial cues for radiological threats. Broadband thermal imaging and visible CCD cameras which are capable of detecting but not identifying chemical and biological clouds, as well as an acoustic sensor, were also explored as cueing mechanisms for UAV deployment.

Data from the tests will be presented showing that the UAV sensor was able to locate the ammonia release location and fly downwind of the release point while continuously detecting the ammonia and relaying detection data back to the UAV operator in real-time. The ability of the UAV-based scintillator to detect small sources while either hovering over possible location or landing for longer term sampling will also be demonstrated.

An expansion of the UAV sensor capability to a broader range of target chemicals as well as the conduct of biological sampling will also be discussed.

9455-36, Session 7

Detection of munitions grade g series nerve agents using Raman excitation at 1064 nm

Eric G. Roy, Rigaku Raman Technologies, Inc. (United States); Phillip G. Wilcox, Soren Hoffland, U.S. Army Edgewood Chemical Biological Ctr. (United States); Ian Pardoe, EXCET, Inc. (United States)

Raman spectroscopy is a powerful tool for obtaining molecular structure information of a sample. While Raman spectroscopy is a common laboratory based analytical tool, miniaturization of opto-electronic components has allowed handheld Raman analyzers to become commercially available. These handheld systems are utilized by Military and First Responder operators tasked with rapidly identifying potentially hazardous chemicals in the field. However, one limitation of many handheld Raman detection systems is strong interference caused by fluorescence of the sample or underlying surface which obscures the characteristic Raman signature of the target analyte.

Munitions grade chemical warfare agents (CWAs) are produced and stored in large batches and typically have more impurities from the storage container, degradation, or unreacted precursors. In this work, Raman spectra of munitions grade CWAs were collected using a handheld Raman spectrometer with a 1064 nm excitation laser. While Raman scattering generated by a 1064 nm laser is inherently less efficient than excitation at shorter wavelengths, high quality spectra were easily obtained due to significantly reduced fluorescence of the munitions grade CWAs. The spectra of these less pure, but more operationally relevant, munitions grade CWAs were then compared to spectra of CASARM grade CWAs, as well as Raman spectra collected using the more common 785 nm excitation laser.

9455-37, Session 8

A molecularly imprinted polymer (MIP)-coated microbeam MEMS sensor for chemical detection

Ellen L. Holthoff, U.S. Army Research Lab. (United States); Lily Li, Kimberly L. Turner, Tobias Hiller, Univ. of California, Santa Barbara (United States)

Recently, microcantilever-based technology has emerged as a viable sensing platform due to its many advantages such as small size, high sensitivity, and low cost. However, microcantilevers lack the inherent ability to selectively identify hazardous chemicals (e.g., explosives, chemical warfare agents). The key to overcoming this challenge is to functionalize the top surface of the microcantilever with a receptor material (e.g., a polymer coating) so that selective binding between the cantilever and analyte of interest takes place. Molecularly imprinted polymers (MIPs) can be utilized as artificial recognition elements for target chemical analytes of interest. Molecular imprinting involves arranging polymerizable functional monomers around a template molecule followed by polymerization and template removal. The selectivity for the target analyte is based on the spatial orientation of the binding site and covalent or noncovalent interactions between the functional monomer and the analyte. In this work, thin films of sol-gel-derived xerogels molecularly imprinted for TNT and dimethyl methylphosphonate (DMMP), a chemical warfare agent stimulant, have demonstrated selectivity and stability in combination with a fixed-fixed beam microelectromechanical systems (MEMS)-based gas sensor. The sensor was characterized by parametric bifurcation sweep-based tracking.

9455-38, Session 8

A study of single-beam femtosecond MCARS in trace material detection

Stephen D. Roberson, 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. Full identification of these particles has been hampered by the inability to use an information-rich spectroscopic method such as Raman scattering in a flowing aerosol environment due to the time needed to generate a Raman spectrum. Multiplex coherent anti-Stokes Raman spectroscopy (MCARS) has been shown to generate a complete Raman spectrum from the material of interest using a single ultrabroadband pulse to coherently drive multiple molecular vibrations simultaneously. When used in conjunction with a narrow probe pulse, a complete Raman spectrum is created that can be detected in milliseconds. We will report on the MCARS spectra obtained from materials of interest at a distance of 1 m from the sample location. A limit of detection study of the MCARS spectrum of various materials of interest will be also reported as well as a determination of the Raman gain factor of MCARS versus spontaneous anti-Stokes Raman spectroscopy. Additionally, a limit of detection study as a function of the number of pulses used to comprise the CARS spectrum of the materials of interest will be presented.

9455-39, Session 8

Differential excitation spectroscopy for detection of chemical threats: DMMP and thiodiglycol

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Differential Excitation Spectroscopy (DES) is a new pump-probe detection technique which characterizes molecules based on a multi-dimensional parameterization of the rovibrational excited state structure, pump and probe interrogation frequencies, as well as the lifetimes of the excited states. Under appropriate conditions, significant modulation of the ground state can result. DES results provide a unique, simple mechanism to validate and understand various molecules in support of relevant science. In addition, the DES multi-dimensional parameterization provides an identification signature that is highly unique and has demonstrated high levels of immunity from interferents, providing significant practical value for high-specificity material identification.

Dimethyl methylphosphonate (DMMP) is used as a simulant for G series nerve agents and thiodiglycol as a simulant for sulfur mustard (HD). Ab initio calculations were performed on DMMP for various rovibrational states up to $J' \leq 3$ and validated experimentally, demonstrating good agreement between theory and experiment and the very specific responses generated. Thiodiglycol was investigated empirically. Optimal detection parameters were determined and mixtures of the two materials were used to demonstrate the immunity of the DES technique to interference from other materials, even those whose IR spectra show significant overlap.

9455-40, Session 8

Breadboard sized photo-acoustic spectroscopy system using an FPGA based lock-in amplifier

John F. Schill, U.S. Army Research Lab. (United States)

Over the past several years we have developed a photo-acoustic spectroscopic (PAS) technique for trace gas detection that is capable of parts per million (ppm) detection limits. The desire to reduce the size of the system has lead to several efforts that have reduced the size of the various components of the system. We have reduced the dimensions of the resonant cell to micrometer scale (MEMS). We have worked with Daylight Solutions to reduce the size of the tunable quantum cascade laser (QCL) used in the system. In this paper we demonstrate the reduction in size of the entire system to a 12" x 12" footprint. We do this by implementing the lock-in amplifier on a field programmable gate array (FPGA) demonstration board that is also capable of acting as the system controller and data output device. We briefly describe the digital lock-in amplifier and sketch our implementation on the FPGA. We go on to compare the spectroscopic data we collected using this system with data we collected using a large rack mounted Stanford Research Systems SR830 lock-in amplifier and a PC.

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9456-1, Session 1

Detection of chemicals using quantum cascade laser spectroscopy *(Keynote Presentation)*

Panos G. Datskos, Marissa E. Morales-Rodríguez, Phillip Bingham, Larry R. Senesac, David Graham, Ilia Ivanov, Kenneth W. Tobin Jr., Oak Ridge National Lab. (United States)

No Abstract Available

9456-2, Session 1

Demonstration of novel high-power acoustic through-the-wall sensor

Franklin Felber, Starmark, Inc. (United States)

An acoustic sensor, capable of detecting and tracking persons through the steel walls of cargo containers, trailer truck bodies, and train cars, has been developed and demonstrated. The high-power acoustic through-the-wall sensor is based on a new concept for narrowband mechanical-impact acoustic transmitters and matched resonant receivers. The lightweight, compact, and low-cost transmitters produce high-power acoustic pulses at one or more discrete frequencies with very little input power, and can be battery-operated. A breadboard impact-transmitter and matched-receiver system that detected human motion through thick walls with only rudimentary signal processing is described, and results are presented.

The foremost advantage of acoustic through-the-wall sensors over radar and gamma-ray sensors is that sound penetrates metal walls almost as well as it penetrates other wall materials, and does so with harmless non-ionizing radiation. Another significant advantage over ultra-wideband (UWB) radar sensors is that acoustic sensors are sensitive to motions smaller than 1/10 of a wavelength, and so can detect stationary persons by their breathing motion alone. Besides these, other attractive features of the acoustic sensor and its signal processing include: high-resolution locating and tracking; portability; low cost; quick and easy preparation and deployment; near-real-time data processing and display; and no damage or changes to the wall. These features provide a robust stand-alone through-the-wall surveillance capability or an excellent complement to a radar sensor.

The new impact-transducer concept is particularly well suited for efficiently and inexpensively producing and coupling high-power acoustic pulses into walls. The concept is based on the discovery that, with proper coupling to a wall, a properly designed thin plate transduces a mechanical impulse to acoustic energy in a wall with high efficiency at the resonant mode frequencies of the plate. Optimal coupling of the transmitter to the wall is achieved with sub-millimeter spacing of the resonant plate from the wall. The principal advantage of mechanical impact transducers is that the energy for each pulse is accumulated over long times at low powers, like a mousetrap, and therefore can be operated with ordinary batteries and no power conditioning.

The through-the-wall system advances reported include: (i) a new mechanical transmitter that is compact, lightweight, low-cost, and can operate on battery power, yet produces acoustic pulses in walls at one or more frequencies that are orders of magnitude more powerful than comparable alternatives; (ii) a resonant receiver matched to the transmitter and designed for efficient coupling to walls and for enhancing with multiple sensors the signal-to-noise ratio (S/N) of the received signal before signal processing; (iii) effective configurations for efficiently coupling the transmitter and matched receiver to walls; (iv) methods of signal processing that increase S/N by several additional tens of dB; (v) algorithms used for real-time through-the-wall tracking of multiple persons; and (vi) a conceptual design of an acoustic through-the-wall sensor, costing about $10,000 per unit and capable of remotely and non-intrusively scanning steel cargo containers for stowaways at a rate of two containers per minute.

9456-3, Session 1

The use of short and wide x-ray pulses for time-of-flight x-ray Compton scatter imaging in cargo security

Nick Calvert, Marta M. Betcke, Univ. College London (United Kingdom); John R. Cresswell, Univ. of Liverpool (United Kingdom); Alick N. Deacon, The Univ. of Manchester (United Kingdom); Anthony J. Gleeson, Science and Technologies Facilities Council (United Kingdom); Daniel S. Judson, Univ. of Liverpool (United Kingdom); Peter Mason, Rapiscan Systems Ltd. (United Kingdom); Peter A. McIntosh, Science and Technologies Facilities Council (United Kingdom); Edward J. Morton, Rapiscan Systems Ltd. (United States); Paul J. Nolan, Univ. of Liverpool (United Kingdom); James Ollier, Mark G. Procter, Rapiscan Systems Ltd. (United Kingdom); Robert D. Speller, Univ. College London (United Kingdom)

In conventional Compton scatter imaging for Cargo security screening, the image is formed by accumulating photons scattering back from the object upon illumination with a pencil beam of x rays. Using a pulsed x-ray source and measuring the time-of-flight (TOF) of the scattered photons, the point of interaction can be determined, assuming a single scatter. Sweeping a pencil beam of x rays over the object under inspection and recording the TOF can lead to three dimensional image formation of cargo containers and their contents. A short pulse width (piceosecond) x-ray source allows for direct measurement of the TOF of the photons, and trivial reconstruction of the interaction point. A longer pulse width (100's of nanoseconds) also allows for reconstruction of the interaction point, after deconvolution of the temporal profile of the source pulse. Preliminary experiments have been performed using the picosecond pulse length Versatile Electron Linear Accelerator (VELA) situated at STFC Daresbury, UK, measuring the TOF of photons scattering from a set of test objects. A full width at half maximum of 12 cm was achieved for a 5 cm thick plastic test object, when using a single CeBr3 detector in the presence of a high radiation background. Results from further experiments, measuring the resolution achievable with such a technique, using an array of plastic scintillator detectors at VELA will be presented. Resolution results from measurements using a conventional wide pulse x-ray source will also be presented.

Topical Area: Concealed Weapons and Through-the-Wall Sensor Technologies and Systems.

9456-4, Session 1

Consideration of the use of visible light 3D scanning for prisoner contraband possession assessment and other similar purposes

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

The assessment of those being involuntarily confined for contraband and other purposes, whether in the context of a civilian criminal detention facility or detention of warfighters is inherently problematic. Some individuals may desire to, for a number of purposes, retain objects beyond screening. These objects may range from benign to weapons or other objects that could injure other detainees or which, in the context of warfighters, may be detrimental to security or defense objectives in other ways. Current techniques to identify these items (or assert the lack of contraband possession) are invasive to the detainees and demonstrably ineffective in certain circumstances.

A variety of techniques have been proposed for contraband detection, ranging from radiative scanners to manual search techniques. This paper describes the prospective use of a visible light 3D scanner for checkpoint assessment purposes. It contrasts the invasiveness of this technology with conventional techniques, considering the competing rights of the detainees to personal dignity and diminished, but existent, privacy rights. United States law regarding detainee searches is reviewed to identify any prospective compliance hurdles for a 3D scanning solution as well as prospective benefits that this non-invasive technique may provide (relative to what can be performed manually under law). The use of visible light, as compared to other prospective scanning solutions, is considered (from both technological and legal implication perspectives) and hybrid solutions are considered. The value of the color data produced by the scanner is also discussed. The paper considers next steps for the use of this type of technology, before concluding.

9456-5, Session 1

Optically transparent superhydrophobic coatings for enhanced performance sensing and CSP and CPV power generations

Scott R. Hunter, D. Barton Smith, Georgios Polizos, Daniel A. Schaeffer, Panos G. Datskos, Oak Ridge National Lab. (United States)

No Abstract Available

9456-6, Session 1

Ultra-strong and electrically conductive graphene fibers

Panos G. Datskos, Ivan Vlassiouk, Oak Ridge National Lab. (United States)

No Abstract Available

9456-7, Session 2

Acoustic and infrared active shooter detection and reporting

Ron Fowler, Chris Connors, Shooter Detection Systems LLC (United States)

No Abstract Available

9456-9, Session 2

Target plane projectile location sensor system

Slobodan Rajic, William R. Lawrence, Panos G. Datskos, Oak Ridge National Lab. (United States); Ross W. Towers, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No Abstract Available

9456-10, Session 3

A low-cost FMCW radar for footprint detection from a mobile platform

David Boutte, Paul Taylor, AKELA, Inc. (United States); Allan Hunt, AKELA Inc. (United States)

Footprint and human trail detection in rugged all-weather environments is an important and challenging problem in perimeter security, passive surveillance and reconnaissance areas. To address the challenges a low cost wideband frequency-modulated continuous wave (FMCW) radar operating at 33.4GHz – 35.5GHz has been developed which is capable of detecting footprints and footprint trails on unimproved roads from a moving vehicle. The system also has applications to personnel detection through light foliage. It is based around a low cost digital signal processor (DSP) that makes important operating parameters reconfigurable and allowing for frequency sweep linearization, a key technique developed to increase footprint signal-to-noise ratio (SNR). Tuning a voltage controlled oscillator (VCO) over a wide bandwidth introduces a non-linear frequency response into an FMCW radar system which, if uncorrected, causes blurring in target-receive signatures and overall SNR degradation. By pre-distorting the VCO tuning waveform the overall response can be corrected. In addition to footprint detection, the same technology and system is applicable to personnel detection at standoff distances >50m through light brush/foliage.

This paper discusses the design, DSP implementation and experimental results of a low-cost FMCW radar for mobile footprint detection. A technique for wideband sweep linearization is detailed along with system performance metrics and experimental results showing receive-SNR from footprint trails in sand and on unimproved dirt roads. The results show that there is sufficient receive-SNR to detect even shallow footprints (~1cm) when using the sweep linearization technique. Similarly experimental results detailing system performance against moving targets are also shown.

9456-11, Session 3

Optically resonant subwavelength films for tamper-indicating tags and seals

Kyle J. Alvine, Jonathan D. Suter, Bruce E. Bernacki, Wendy D. Bennett, Pacific Northwest National Lab. (United States)

We present the design, modeling and performance of a proof-of-concept tamper indicator that exploits newly-developed subwavelength-patterned

films. These films have a nanostructure dependent resonant optical reflection that is wavelength, angle, and polarization dependent. As such, they can be tailored to fabricate overlay transparent films for tamper indication and authentication of sensitive or controlled materials not possible with currently-known technologies. An additional advantage is that the unique optical signature is dictated by the geometry and fabrication process of the nanostructures in the film, rather than on the material used. The essential structure unit in the subwavelength resonant coating is a nanoscale Open-Ring Resonator (ORR). This building block is fabricated by coating a nanoscale template with metal to form a shell-like structure. The curved metallic shell structure has a cross-section with an intrinsic capacitance and inductance and is thus the optical equivalent to the well-known "LC" circuit where the capacitance and inductance are determined by the nanoshell dimensions. For structures with sub 100 nm scale, this resonance occurs in the visible electromagnetic spectrum, and in the IR for larger shells. Tamper indication would be visible though misalignment of the angular dependence of the features in the film. It is additionally possible to add in intrinsic oxidation and strain sensitive matrix materials to further complicate tampering and counterfeiting. Cursory standoff readout would be relatively simple using a combination of a near-infrared (or visible) LED flashlight and polarizer or passively using room lighting illumination and a dispersive detector.

9456-12, Session 3

Multi-capability color night vision HD camera for defense, surveillance, and security applications

Francis Pang, e2v Aerospace and Defense, Inc. (United States)

e2v has developed a family of high performance cameras based on our next generation CMOS imagers that provide multiple features and capabilities to meet the range of challenging imaging applications in defense, surveillance, and security markets.

Two resolution sizes are available: 1920x1080 with 5.3um pixels, and an ultra-low light level version at 1280x1024 with 10um pixels. Each type is available in either monochrome or e2v's unique bayer pattern color version. The camera is well suited to accommodate many of the high demands for defense, surveillance, and security applications: compact form factor (SWAP+C), color night vision performance (down to 10-3 lux), ruggedized housing, Global Shutter, low read noise (<6e- in Global shutter mode and <2.5e- in Rolling shutter mode), 60 Hz frame rate, high QE especially in the enhanced NIR range (up to 1100nm). Other capabilities include active illumination and range gating.

This paper will describe all the features of the sensor and the camera. It will be followed with a presentation of the latest test data with the current developments. Then, it will conclude with a description of how these features can be easily configured to meet many different applications. With this development, we can tune rather than create a full customization, making it more beneficial for many of our customers and their custom applications.

9456-13, Session 3

Analysis of a mutual assured destruction-like scenario with swarms of non-recallable autonomous robots

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

This paper considers the implications of the creation of an autonomous robotic fighting force without recall-ability which could serve as a deterrent to a 'total war' magnitude attack. This style of robot would be programmed with targeting parameters and could persistently attack the designated enemy or enemy targets, without human intervention, once unleashed. While the technology required for this type of system is not currently available (target classification, in particular, is one area that is lacking), the technological limitations are not tremendous and it is likely that this type of system (particularly for use by a non-state actor acting within a state in which the non-state actor perceived almost everything as a prospective target, irrespective of its legitimacy as a target of war under international law) could be fielded within years, not decades. The paper discusses the technical considerations for this type of robotic system and the limited enhancements to current technologies required to current technologies (particularly UAVs) needed to create such a system.

Particular consideration is paid to how the introduction of this type of technology by one actor could create a need for reciprocal development. The parallels of this scenario to the nuclear-weapon-based mutual assured destruction phenomenon are considered and conclusions are drawn. The differences between these two scenarios (particularly in terms of the scope of warfighting and granularity of targeting) are discussed. The impact of these differences on state and non-state actors to deploy such a system is, from this, considered. Finally, the prospective utilization of this type of technology by non-state actors and the potential for this scenario occurring's impact on state actors is discussed, before concluding.

9456-14, Session 3

Performance of a buried microphone to detect voice and footsteps

Thyagaraju Damarla, U.S. Army Research Lab. (United States)

Traditionally, both acoustic and seismic sensors are used as a part of modern unattended ground sensor (UGS) suite. Acoustic sensors capture the high frequency content of human voice, automobile, airplanes, etc., and their unique features are used to discriminate them. Whereas, the seismic sensors are primarily used to detect vibrations caused by people walking and vehicles traveling in the vicinity of the sensor. Both sensor data are analyzed and the results are fused to get better detection statistics 1. However, the UGS system once deployed should last for several months before changing the batteries. This implies, one should use fewer sensors that consume very little power. Towards this goal, experiments were made to replace the performance of both seismic and acoustic sensors by a single buried microphone. The performance of the buried microphone is compared with the performance of a seismic sensor in detection of footfalls and with a microphone that is above ground for high frequency fidelity. Moreover, buried microphone can be used for stealth operations.

We performed several experiments to detect human activity near a culvert. Two buried microphones, one at the bottom of a culvert near its entrance and another just above the culvert are used for monitoring the culvert. We also buried two seismic sensors next to the microphones and mounted a microphone above the ground to assess the quality of the buried microphones. Single channel source separation techniques, such a principle component analysis, non-negative matrix factorization, are used to separate the subsurface (seismic) and above surface (acoustic) signals from the signals of buried microphone. The performance of the buried microphone is presented on the actual data collected in the field.

9456-15, Session 3

Surveillance systems for intermodal transportation

Sergej Jakovlev, Klaipeda Univ. (Lithuania); Miroslav Voznak, VŠB-Technical Univ. of Ostrava (Czech Republic); Arunas Andziulis, Klaipeda Univ. (Lithuania)

Intermodal container monitoring is considered a major security issue in many major logistic companies and countries worldwide. Current representation of the problem, we face today, originated in 2002, right after the 9/11 attacks. Then, a new worldwide Container Security Initiative (CSI, 2002) was considered that shaped the perception of the transportation operations. Now more than 80 larger ports all over the world contribute to its further development and integration into everyday transportation operations and improve the regulations for the developing regions. Although, these new improvements allow us to feel safer and secure, constant management of transportation operations has become a very difficult problem for conventional data analysis methods and information systems.

Integration of many new Information and Communication Technologies (ICT) and other safety and security regulations in existing cargo handling operations and processes is likely to be the main solution. As an example, some industrial applications already include new RFID standards, but with limited applicability. The choice of the applied communication technology often depends on the used frequency. Frequency reflects numerous factors, including not only technical considerations, but also international availability and economic considerations. One of the most known monitoring systems is the ConTracer. But even this known product is applied mostly in theory, to evaluate the potential risks and their prevention methods. Research is now being done to estimate the efficiency of the installations in terms of cost. Still, this main solution has many research related communication and data analysis problems.

In general, the developed systems use different communication and integration standards, therefore, many authors suggest using only separate systems and technologies rather than complex integrated solutions. There are several application scenarios and appropriate technologies that need to be considered. Firstly, we have a scenario where containers are stored on a ship. Next, we have a scenario where containers are stored in a container terminal. Finally, these containers are transported via truck and trains to their destinations. So, appropriate technologies are applied at each separate scenario. They include application of WSN, RFID, GPS/Galileo, video surveillance systems and many other methods and data analysis algorithms that are strictly formalized and standardized.

In our research, we have focused on presenting a new concept container monitoring approach by using an intellectual agent in a conceptual deployed middleware module for the WSN. The module sends alert information only when a real threat takes place.

9456-16, Session 3

Unmanned aerial vehicles (UAVs): a new tool in counterterrorism operations?

Mehmet F. Dörtbudak, Turkish Air War College (Turkey)

Terrorism is not a new phenomenon to the world, yet it remains difficult to define and to counter. Countering terrorism requires several measures that must be taken at the same time, however, counterterrorism strategies of many countries mostly depend on military measures.

In the aftermath of the 2001 terrorist attack on the Twin Towers of the World Trade Center, the United States (U.S.) has started and led the campaign of Global War on Terrorism. They have invaded Afghanistan and Iraq and have encountered insurgencies run by terrorist organizations, such as al-Qaeda and its affiliates. The insurgencies have increased in effectiveness over the years. The U.S., though, has made significant improvements in disrupting and destroying terrorist organizations' activities. The U.S. made the utilization of Air and Space Power very intensively during these operations. In order to implement operations; Intelligence, Surveillance, and Reconnaissance (ISR) assets were used to collect the necessary information. Before the successful insertion of a small number of U.S. Special Operation Force (SOF) teams into Afghanistan, the U.S. Air Force attacked al-Qaeda and Talibans' targets such as infrastructure, airfields, ground forces, command-control facilities etc. As soon as the U.S. troops got on the ground and started to marshall to Kabul, the Air Force supported them by attacking the targets determined by the ground forces. The Air Force continued to carry out the missions and played a significant role to achieve the objective of operation during all time.

This is not the only example of utilization of Air and Space Power in counterterrorism and counterinsurgency operations. All around the world, many countries have also made the utilization of Air Power in different missions ranging from ISR to attacking. Thinking that terrorism has a psychological dimension and loosing a pilot during operations may result in decreasing the population support to operations, Unmanned Aerial Vehicles (UAVs) started to be used by practitioners and took priority over other assets. Although UAVs have been on the theatre for a long time used for ISR mission in conventional conflicts, with the advent of drones, UAVs have also started to be used for attack missions in counterterrorism operations.

In this study, it is aimed to determine whether UAVs are convenient assets that can be used in counterterrorism operations. The study starts by examining the term terrorism and counterterrorism and discusses the role of the Air and Space Power in counterterrorism operations. After proposing that UAVs are convenient assets for counterterrorism operations, it continues by explaining types and common usage concepts of UAVs. The advantages and disadvantages of UAVs are put forward from the counterterrorism operations' perpectives. It finally examines the utilization of UAVs in counterterrorism operations. In this context, as much as obtained from open sources, countries' roadmaps, usage concepts, experience, and current structure are examined to determine whether UAVs are convenient assets in counterterrorism operations. When the advantages of UAVs and the disadvantages of manned systems analyzed, and other findings of our survey show us that UAVs will be increasingly used in counterterrorism operations.

9456-54, Session 3

Packet-based serial link realized in FPGA dedicated for high-resolution infrared image transmission

Grzegorz Bieszczad, Military Univ. of Technology (Poland)

In this article the external digital interface specially designed for thermographic camera built in Military University of Technology is described. The aim of article is to illustrate challenges encountered during design process of thermal vision camera especially related to infrared data processing and transmission. Article explains main requirements for interface to transfer Infra-Red or Video digital data and describes the solution which we elaborated based on Low Voltage Differential Signalling (LVDS) physical layer and signalling scheme.

Elaborated link for image transmission is built using FPGA integrated circuit with built-in high speed serial transceivers achieving up to 2500Gbps throughput. Image transmission is realised using proprietary packet protocol. Transmission protocol engine was described in VHDL language and tested in FPGA hardware. The link is able to transmit 1280x1024@60Hz 24bit video data using one signal pair. Link was tested to transmit thermal-vision camera picture to remote monitor. Construction of dedicated video link allows to reduce power consumption compared to solutions with ASIC based encoders and decoders realising video links like DVI or packed based Display Port, with simultaneous reduction of wires needed to establish link to one pair.

Article describes functions of modules integrated in FPGA design realising several functions like: synchronisation to video source, packetisation of video stream, interfacing transciever modulea and dynamic clock generation for video standard conversion.

9456-55, Session 3

Mobile, portable lightweight wireless video recording solutions for homeland security, defense, and law enforcement applications

Matthew Sandy, Nanometrology LLC (United States)

No Abstract Available

9456-17, Session 4

Deep learning of behaviors *(Keynote Presentation)*

George Cybenko, Thayer School of Engineering at Dartmouth (United States)

No Abstract Available

9456-18, Session 4

National Institute of Justice: Science and Technology Office initiatives *(Keynote Presentation)*

William A. Ford, U.S. Dept of Justice (United States)

No Abstract Available

9456-19, Session 5

Quantification of moving target cyber defenses

Katheryn A Farris, George Cybenko, Thayer School of Engineering at Dartmouth (United States)

No Abstract Available

9456-20, Session 5

Enterprise scale cyber risk assessment and management

Jeff Hughes, Tenet 3, LLC (United States); George Cybenko, Thayer School of Engineering at Dartmouth (United States)

No Abstract Available

9456-21, Session 5

Image encryption by redirection and cyclical shift

Artyom M. Grigoryan, Bryan A. Wiatrek, The Univ. of Texas at San Antonio (United States); Sos S Again, University of Texas at San Antonio (United States)

In this paper, we present a novel method for encrypting and decrypting large amounts of data such as 2-D images, both gray-scale and color, without the loss of information using private keys of varying lengths. The proposed method is based on the concept of the tensor representation of image and splitting the two-dimensional discrete Fourier transform by 1-D DFTs of signals from the tensor representation, or transform. The splitting of the transform is accomplished in a three dimension space, namely on the 3-D lattice placed on the torus. Each splitting-signal of the image defines the 2-D DFT along the frequency-points located on the spirals on the torus. Spirals have different form and cover the lattice on the torus in a complex form, which makes them very effective when moving data through the spirals and between them, and data along the spirals. The encryption consists of several iterative applications of the mapping the 3-D torus into the several ones of small sizes, and rotates and moves the data around the spirals on all tori. The encryption results in the image which is uncorrelated. The decryption algorithm uses the encrypted data and processes them in inverse order with an identical number of iterations. The proposed method can be extended to encrypt and decrypt documents as well as other types of digital media. Simulation results of the purposed method are presented to show the performance for image encryption. The comparison of the proposed method with previously used methods of encryption is given.

9456-22, Session 5

An exact computational method for performance analysis of sequential test algorithms for detecting network intrusions

Xinjia Chen, Frederick W. Lacy, Patrick Carriere, Southern Univ. and A&M College (United States)

Sequential test algorithms are playing increasingly important roles for quick detecting network intrusions such as portscanners. In view of the fact that such algorithms are usually analyzed based on intuitive approximation or asymptotic analysis, we develop an exact computational method for the performance analysis of such algorithms.

Our method can be used to calculate the probability of false alarm and average detection time up to arbitrarily prespecified accuracy. We establish a recursive method for efficiency of computation. We propose to use Chernoff bounds to ensure the accuracy of computation. In particular, we apply our method to Threshold Random Walk Algorithm for detecting port scanners. A path counting technique is proposed for further reducing the computational complexity.

9456-23, Session 6

Bayesian truthing as experimental verification of C4ISR sensors

Tomasz P. Jannson, Thomas C. Forrester, Physical Optics Corp. (United States); Volodymyr Romanov, Wenjian Wang, Thomas Nielsen, Andrew Kostrzewski, Physical Optics Corp (United States)

In this paper, the general methodology for experimental verification of C4ISR sensor performance for both analog and digitized sensors, is presented, based on Bayesian inference, in general, and binary sensing, in particular. This methodology, called Bayesian Truthing, named after Radar Truthing, defines Performance Metrics for binary sensors in such diversified areas as: optics, medicine, law enforcement, C3ISR, QC, ATR (Automatic Target Recognition), Homeland Security, defense, terrorism related events, and many others. For Bayesian Truthing, the sensing medium itself is not what is truly important; it is how the decision process is affected which defines what is, and what is not, target or noise.

Two conditions define binary sensor and Bayesian Truthing methodology: binary decision space and descrete (quantal) event space, where anomalous events are signals and non-anomalous (regular) events are noise. The basic Figures of Merit of this C3I-decision generation tools, are: PPV (Positive Predictive Value), Probability of False Alarm (PFA), Probability of Detection (PoD), and number of false no-alarms (or, target misses). In this paper, we show how these FoMs can be optimized, using two examples: C3ISR-optical, and medical (mammography) ones, the latter well-established PPV-based one.

For experimental verification of sensor performance optimization purposes, the basic challenge, addressed in this paper, is the rare occurrence of targets (signals) within (quantal) event space; i.e. anomalous events were rare. Then, the reducing of target misses usually increases false alarm rate (PFA).

The long-term potential benefits: due to Bayesian Truthing, sensor's performance can be evaluated in a standardized, more uniform way, independent on specific sensing medium.

9456-24, Session 6

Stochastic optimization of space-time constellations

Xinjia Chen, Patrick Carriere, Frederick W. Lacy, Southern Univ. and A&M College (United States)

For wireless data communication systems employing multiple antennas, space-time codes play crucial roles for fast transmission of data with accuracy and bandwidth efficiency. Motivated by the large size of constellations of space-time codes and the resultant computational complexity, we develop a stochastic approach for the optimization of space-time constellations. We use union bounds of block error rate as performance measures of the space-time codes. To overcome the computational complexity, we propose to transform the performance measure into the mean of a bounded random variable and establish a statistical method for the estimation of such mean and its gradients with respect to parameters. A stochastic gradient descent method is developed for optimizing space-time codes. Such stochastic techniques are applied to obtain high performance space-time codes of large constellation sizes.

9456-25, Session 6

Improving situation awareness with the Android team awareness kit (ATAK)

Kyle Usbeck, Matthew Gillen, Joseph P. Loyall, Andrew Gronosky, Raytheon BBN Technologies (United States); Joshua Sterling, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Ralph L. Kohler Jr., Air Force Research Lab. (United States); Kelly Hanlon, Andrew Scally, WinTec Arrowmaker, Inc. (United States); Richard Newkirk, David Canestrare, Air Force Research Lab. (United States)

To make appropriate, timely decisions in the field, Situational Awareness (SA) needs to be conveyed in a decentralized manner to the users at the edge of the network as well as (optionally) at operations centers. Sharing real- time SA efficiently between command centers and operational troops poses many challenges, including handling heterogeneous and dynamic networks, resource constraints, and varying needs for the collection, dissemination, and display of information, as well as recording that information.

A mapping application that allows teams to share relevant geospatial information efficiently and to communicate effectively with one another and command centers has wide applicability to many vertical markets across the Department of Defense, as well as a wide variety of federal, state local, and non-profit agencies that need to share locations, text, photos, and video.

This paper describes the Android Team Awareness Kit (ATAK), an advanced, distributed tool for commercial- off-the-shelf (COTS) mobile devices such as smartphones and tablets. ATAK provides a variety of useful SA functions for soldiers, law enforcement, homeland defense, and civilian collaborative use; including mapping and navigation, range and bearing, text chat, force tracking, geospatial markup tools, image and file sharing, video playback, fire control, site surveys, and many others. This paper describes ATAK, the SA tools that ATAK has built-in, and the ways it is being used by a variety of military, homeland security, and law enforcement users.

9456-26, Session 6

Adaptive randomized algorithms for analysis and design of control systems under uncertain environments

Xinjia Chen, Southern Univ. and A&M College (United States)

We consider the general problem of analysis and design of control systems in the presence of uncertainties. We treat the uncertainties that affect the performance of control systems as random variables. We consider the probability that the control system fails to satisfy the pre-specified requirements. We develop adaptive sequential randomized algorithms for estimating such a probability with guaranteed accuracy and confidence level. Moreover, we establish stochastic optimization techniques for seeking the controller with the lowest failure probability from a set of parameterized systems. We develop methods for investigating the optimality and computational complexity of such algorithms.

9456-27, Session 7

Vulnerabilities in GSM technology and feasibility of selected attacks

Miroslav Voznak, Martin Prokes, Lukas Sevcik, Jaroslav Frnda, VŠB-Technical Univ. of Ostrava (Czech Republic); Homer Toral-Cruz, University of Quintana Roo (Mexico); Zdenka Chmelikova, VŠB-Technical Univ. of Ostrava (Czech Republic); Peppino Fazio, University of Calabria (Italy); Miralem Mehic, Martin Mikulec, VŠ0B-Technical Univ. of Ostrava (Czech Republic)

Global System for Mobile communication (GSM) is the most widespread technology for mobile communications in the world and serving over 7 billion users. Since first publication of system documentation there has been notified a potential safety problem's occurrence. Selected types of attacks, based on the analysis of the technical feasibility and the degree of risk of these weaknesses, were implemented and demonstrated in laboratory of the Department of telecommunications in Ostrava, Czech Republic. These vulnerabilities were analyzed and afterwards possible attacks were described. These attacks were implemented using open-source tools, software programmable radio USRP (Universal Software RadioPeripheral) and DVB-T (Digital Video Broadcasting – Terrestrial) receiver. GSM security architecture is being scrutinized since first public releases of its specification mainly pointing out weaknesses in authentication and ciphering mechanisms. Short description of realized attacks:

1. First attack described in this paper presents implementation of faked GSM base station (BTS) that is built on software radio platform USRP and open-source implementation of GSM protocol stack. This allows an attacker to act as a real GSM BTS in restricted radio spectrum GSM 900/1800 and makes the mobile phones to communicate with it.

2. Second type of attack is eavesdropping of communication in real GSM network using low-cost device USB DVB-T tuner. Data captured with usage of software tool rtl-sdr consists of GSM network signaling and traffic communication between BTS and mobile phone. There is also de-scribed a way how to obtain session ciphering key that allows an attack-er to decrypt SMS messages as well as voice calls.

3. Last type of attack is catching identity information of subscribers using tool IMSI catcher. IMSI (International Mobile Subscriber Identity) is sensitive information that identifies subscriber's SIM card. Knowledge of IMSI by an attacker is big security issue that allows tracking of sub-scribers in its area. This and first attack can be performed due to lack of two-way authentication between GSM and mobile station allowing to impersonate real network BTS with only two parameters MCC (Mobile country code) and MNC (Mobile network code).

This contribution also summarizes practically proofed and used scenarios that are performed using open-source software tools and variety of scripts mostly written in Python.

9456-28, Session 7

PACT DSS: a decision support system for privacy impact assessment of future security investments

Stelios C.A. Thomopoulos, Dimitris M. Kyriazanos, Anastassios Bravakis, National Ctr. for Scientific Research Demokritos (Greece); Olga Segou, NCSR Demokritos (Greece)

The PACT Decision Support System (DSS) is a tool for assessing the impact of future security technology investments and deployments in terms of privacy, ethics, social acceptance and public perception. It aims at assisting the decision process of experts through efficient visualisation and interaction powered by the software implementation of PACT's theoretical and empirical findings.

The DSS methodology begins with the surveillance technology scenario and use case analysis, identifying in the process the assets to protect. As a next step, legal requirements as well as ethical and societal considerations (the latter being based on the PACT empirical results) are analysed and correlated in order to produce threat and impact assessment metrics. The metrics are then consulted in order to build relevant decision trees which will support the user in his/her decision making for the selected security investment.

The PACT DSS is context-specific and it is based on the three contexts specified in the PACT survey, namely the Travel, Healthcare and Internet. However, the PACT DSS is modular and extensible, having the ability to integrate future empirical studies in other contexts, or enrich the existing contexts without overhead or need for extended offline time for the PACT DSS system. To achieve this, the tool is powered by an extensible data model and data management algorithms which can adapt the analytical and prediction DSS functionalities to new use cases and datasets.

PACT DSS aims at the following user-perspective success criteria:

i. Reduction on average decision process time (including collaboration with other users)

ii. Improving decision specific context visibility & access to necessary knowledge for related security technologies decision making

iii. Reduction on average time for compiling a privacy impact assessment report

iv. Convenience and acceptance of the produced PACT impact assessment report

v. Usability & User friendliness

vi. Cost effectiveness (value for money)

It should be clearly noted that the PACT DSS is not a legal instrument tool responsible of taking or validating the legality of the user's decisions. The user is the expert responsible of taking decisions, and the PACT DSS is a convenient and user-friendly tool to help him reach to the decision faster and with a better view of associated parameters, knowledge and arguments.

It is important to highlight that the design of the PACT DSS is user-driven, and decisions are taken by the users themselves, with the system supporting the process through multiple modalities and presenting quantitative and qualitative information regarding the impact of each decision path.

1 European Research Project PACT: Public perception of security and privacy: Assessing knowledge, Collecting evidence, Translating research into action, FP7-SECURITY-Call4-285635 Capability Project, http://www.projectpact.eu/

9456-29, Session 7

Anomalies, singularities, and catastrophes in C3ISR systems

Tomasz P. Jannson, Pedram Boghrat, Thomas C. Forrester, Thomas Nielsen, Andrew A. Kostrzewski, Physical Optics Corp. (United States); Kevin Walter, Physical Optics Corp (United States)

The effectiveness of Decision Generation Tools depends on successful extraction of essential events from, usually very large, event space. In this paper, we propose a new approach of extraction of essential events, based on topologic visualization of essential (or, rather anomalous) events in binary event space, called by us Digital Decision Support (DDS) tools. In this paper, we provide topological visualization of these tools, based on so-called Digital Topologic Singularities (DTS), in general, and those of catastrophes, in particular.

DTS can be categorized within three (3) major types: Threshold DTS (prior art of-the-expectation incidents); Linear DTS (functions maxima, minima, inflection points, etc.); non-Linear DTS, the latter ones being various kinds of mathematical catastrophes, such as fold, cusp, etc. In this paper, we mostly discuss the 3rd DTS category, as well as we compare them with the linear DTS, within heuristic machine learning, idealization, and abstraction. The basic flow chart of DDS includes: regression, smoothing and 2D "analogization" of descrete experimental data; generation of 2D parametric curves; parametrization-to-continuum (PtC) of these curves into surface continuum (i.e., 3D "analogization"); and, final discretization (or, quantization) into non-linear DTS (catastrophes).

In this paper, we discuss topological visualization of singularities and anomalies, in the form of: curves, surfaces, spaces, cross-sections, and projections, in 3D, 4D, and higher spaces.

As a basic physical example, we discuss catastrophes of non-linear harmonic oscillator, generalized into Bayesian Anomalous Events (or, BAEVENTS).

Long-term potential benefits: more effective Decision Generation Tools within Command and Control Systems and Technologies.

9456-30, Session 7

The next generation of command post computing

Ross D Arnold, Aaron J Lieb, Jason M Samuel, Mitchell A Burger, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No Abstract Available

9456-31, Session 7

DXBC: a long distance wireless broadband communication system for coastal maritime surveillance applications

Stelios C.A. Thomopoulos, National Ctr. for Scientific Research Demokritos (Greece); George Vastianos, NCSR Demokritos (Greece)

The field of Homeland Security focuses on the air, land, and sea borders surveillance in order to prevent illegal activities while facilitating lawful travel and trade. The achievement of this goal requires collaboration of complex decentralized systems and services and transfer of huge amount of information between the remote surveillance areas and the command & control centers. It becomes obvious that the effectiveness of the provided security depends highly on the available communication capabilities between the interconnected areas. Although nowadays the broadband communication between remote places is presumed easy because of the extensive infrastructure inside residential areas, it becomes a real challenge when the required information should be acquired from locations where no infrastructure is available such as mountain or sea areas. The Integrated Systems Lab of NCSR Demokritos within the PERSEUS FP7-SEC-2011-261748 project has developed a wireless broadband telecommunication system that combines different communication channels from subGHz to microwave frequencies and provides secure IP connectivity between sea surveillance

vessels and the Command and Control Centers over long distances. The system was deployed in Fast Patrol Boats of the Hellenic Coast Guard that are used for maritime surveillance in sea boarders and tested successfully in two demonstration exercises for irregular migration and smuggling scenarios. This paper describes in detail the system architecture in terms of hardware and software and evaluation measurements of the system communication capabilities.

9456-32, Session 8

Precision tracking of low radar cross-section targets

Amanda Keeshen, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No Abstract Available

9456-33, Session 8

Remote ballistic emplacement of an electro-optical and acoustic target detection and localization system

Aaron West, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

(U) The Sensor Mortar Network (SMortarNet) is a 60mm Intelligence, Surveillance, and Reconnaissance (ISR) mortar designed to give the Squad near real-time situational awareness in uncontrolled non-line-of-sight and beyond-line-of-sight environments with a deployment range up to 3500m. SMortarNet is designed to track targets both acoustically and electro-optically and can fuse tracks across modalities. The system is linked to other mortar nodes and the user via a masterless, frequency-hopping, spread spectrum, ad-hoc mesh radio network.

(U) This paper will discuss SMortarNet in the context of a squad level dismounted soldier, its technical capabilities, and its benefit to the small unit Warfighter. The challenges with ballistic remote emplacement of sensitive components and the on-board signal processing capabilities of the system will also be covered. The paper will also address how the sensor network can be integrated with existing infrastructure for rapid transition to soldier systems.

9456-34, Session 8

Picatinny optical detection system (PODS)

Gerard Gaeta, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No Abstract Available

9456-35, Session 8

Installation as a system

Robert Giarratano, Mike Cazzola, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No Abstract Available

9456-36, Session 8

Flexible fire control system (F2CS)

Jose G. Vergara, U.S. Army Armament Research, Development and Engineering Ctr. (United States); Jonathan Leslie, DHPC Technologies, Inc. (United States)

No Abstract Available

9456-38, Session 9

RF photonics for next-generation electronic warfare *(Keynote Presentation)*

Josh Conway, Defense Advanced Research Projects Agency (United States)

No Abstract Available

9456-39, Session 10

Laser beam propagation through an atmospheric transitional and turbulent boundary layer

Richard A. Katz, Naval Undersea Warfare Ctr. (United States)

No Abstract Available

9456-40, Session 10

Challenges of laser beam propagation near and within the marine boundary layer

Tariq Manzur, Richard A. Katz, Naval Undersea Warfare Ctr. (United States)

No Abstract Available

9456-41, Session 10

Patterning for success

Theresa Baus, Naval Undersea Warfare Ctr. (United States)

No Abstract Available

9456-42, Session 11

Various uses for optical metamaterials

Jose G. Barbosa, Naval Undersea Warfare Ctr. (United States)

No Abstract Available

9456-43, Session 11

Nonlinear acoustic modeling for undersea sensors

Richard A. Katz, Naval Undersea Warfare Ctr. (United States)

No Abstract Available

9456-44, Session 11

Navigational lights color study

Jose G. Barbosa, Naval Undersea Warfare Ctr. (United States)

No Abstract Available

9456-45, Session 11

Fundamentals of optical signal-based MWIR uncooled silicon carbide sensor for DoD/DHS applications

Geunsik Lim, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

No Abstract Available

9456-46, Session 11

Image processing in a maritime environment

Kenneth A. Pietrzak, Naval Undersea Warfare Ctr. (United States)

No Abstract Available

9456-47, Session 11

Sea-air boundary meteorological sensor

Jose G Barbosa, Naval Undersea Warfare Ctr. (United States)

No Abstract Available

9456-48, Session 11

the transition from intelligence cycle to intelligence process: network-centric intelligence in narrow seas

Engin BÜKER, Turkish Naval War College (Turkey)

In defense technologies where the one who is one step ahead is advantageous, the most critical step is predicting the next environment and spectrum of warfare. Defense technologies are developing and changing with an ever increasing acceleration making it difficult to foresee what the battlefield will look like in 20 years and therefore be able to plan for the exploitation of the possibly new areas of operations as well as properly defend against them.

When we take into account the developments and changes with regards to naval warfare, it may be said that the full-spectrum of Naval Operations and the scenarios which will be constituted in the near and medium future (3-20 years) shall be more clarified compare to the other military forces. The concept of network-centric naval warfare and the command control centers have always and will be dependent on surface, subsurface and flying platforms operating miles apart from each other as well as far from shore support. In this way the reliance on a “network-centric intelligence” structure that is fully integrated within this system shall gain infinitely more importance.

This study will offer solutions for the above stated problems about future naval warfare’s need for real-time intelligence and create new types of processes that can operate within traditional intelligence production cycles. The end desire is the incorporating of the disciplines which currently have a place in producing products within this cycle and successfully transiting to future technologies capable of exploiting information in the open seas to operating in narrow seas for NATO Operations.

Outline for the Full Paper

Conventional Intelligence Cycle and Collection Disciplines

Conventional Intelligence Architecture and Building

Necessity for Transition to Intelligence Process and Network-Centric Intelligence (NCI) Structure

NCI Structure Based On Satellite Model in Use

NCI Model Proposal without Use of Satellite for NATO in Narrow Seas

Conclusions

9456-49, Session 12

DETERRENCE OF BALLISTIC MISSILE SYSTEMS AND THEIR EFFECTS ON TODAT’S AIR OPERATIONS

Hasan Durak, Turkish Air Force Academy (Turkey)

Today and in our recent past, the effect-based approach has gained importance in executed air operations. Thus breaking the enemy’s determination and making it more successful in achieving the desired results in near future. Air force is the first option to be chosen in order to defuse the strategic objectives. However, the problems such as the defense of targets and country, radars, range,...etc. becoming as serious problems. At this level ballistic missiles emerge as a strategic weapon. Ultimate emerging technologies that can be guided by the INS and GPS can also be engaged with multiple warheads and reinforced with conventional explosive, ballistic missiles are weapons that can destroy targets with precision. They have the advantage of high speed, being to be easily launched from every platform and not be easily detected by air defense systems as other air platforms. While these are the advantages, there are also disadvantages of the ballistic missiles. The high cost, unavailability of nuclear, biological and chemical weapons, and its limited effect while using conventional explosives against destroying the fortified targets are the disadvantages. The features mentioned above should be considered as limiting the impact of the ballistic missiles. The aim is to impose the requests to enemies without starting a war with all components and to ensure better implementation of the operation functions during the air operations. In this study, effects of ballistic missiles in the future air battle theatre will be discussed in the beginning, during the process and at the end phase of air operations within the scope of an effect-based approach.

9456-51, Session 12

Human factor in future air command and control systems

Fatih Buyruk, Harun R. Altun, Ferhat Pinar, Turkish Air War College (Turkey)

Command and Control systems have became one of the most important elements in the use of air power from the period of First World War to the present time. They're built on several general functions and renewed themselves to the needs of the period. When we look at today's Command and Control systems, we can see that renewal clearly from their names such as C4ISR , C4ISTAR , C5I , C5I2 , C5IMP , C5ISR etc. In addition, today's Command and Control systems find more places in military operations with mentioning such terms; effect-based approach, comprehensive approach, network-centric warfare, information superiority, decision superiority etc. Technology has the biggest role over these terms which are unused until a very short time. The technology is changing very quickly and the area of operations expanded into different areas such as near-space, space, and cyber space. All these advancements show that operational environment of future will have a different understanding then today. In the future air operations, it's expected that unmanned platforms and decision support systems will pervade thus human effects are expected to decline in part. In this article, it's studied if human factor has an accelerator effect or prolonging the duration of sensor-to-shooter cycle and slowing down the whole system on Command and Control systems of future air operations. In the study, it's discussed human effects in advanced Air Command and Control systems of modern countries and international organizations. As a result, it's appeared that air operation's density and sensivity increasing dependence on decision support mechanisms and the interdependence of the human factor and technology is shaped according to the level of the operation.

9456-52, Session 12

Future's operation areas: new-generation suppression enemy air defence (SEAD) elements

Ilker Hazinedar, Turkish Air War College (Turkey)

Since air vehicles took place in the theater of operations, they have become the indispensable elements and the strongest attack power of armed forces. In the following period, with technological development, supersonic aircrafts took place in the operation area and this increased effectiveness of air vehicles much more. Air forces have used these aircrafts during important missions like strategic attack and air defence operations.

On the other hand, decision makers understood that it was not feasible to intercept fighter aircrafts by executing combat air patrol flight missions. Since there is not enough reaction time to intercept the high speed aircrafts, ground stationed Surface to Air Missiles (SAM) system requirement has emerged. Therefore, SAM systems took place in the operation scene as well.

Due to the fact that SAM systems emerged against the attack power, the attack aircrafts are to keep away from the fire of the ground stationed SAM systems. Hence, the requirement of Supression Enemy Air Defence (SEAD) arose. SEAD elements take under suppression the radar of the SAM systems. In this way, attack aircrafts are able to attack without the risk of SAM systems.

The purpose of this study is to find new methods or concepts in order to protect friendly attack aircrafts against ground based surface to air misilles' fires.

Modernization of SAM systems and new generation SAM system producing activities have proceeded with pozitive acceleration. So, current SEAD elements and consepts are not be able to cover the requirements due to the increased SAM system ranges. According to the concepts, SEAD weapons' ranges must be longer than the SAM weapons' ranges to protect friendly aircrafts.

In this study, new concept was offered to overcome the deficiencies of current SEAD concept. The elements of new concepts were put forward. Classic SEAD concept and new generation concepts were assessed by using SWOT analysis technique.

As a result, this study has revealed that, air forces' effectiveness can be enhanced by using new generation SEAD concepts against enemy SAM systems.

9456-53, Session 12

Laser-aided navigation system for GPS-denied navigation and recovery

Brian S. Goldberg, Adsys Controls, Inc. (United States)

The prolific reliance of unmanned aerial systems (UAS) on GPS for navigation has established a key vulnerability point. The ability for jamming and spoofing GPS signals has already been demonstrated and further exemplifies the need for alternative navigation solutions. Adsys Controls' Laser Aided Recovery System (LARS) provides 3D precision navigation with complete independence from GPS and the RF spectrum. This all-weather long range navigation system offers a new solution for A2AD as well as EMCON environments where GPS is vulnerable or RF interference/jamming is susceptible. The LARS architecture will be discussed, as well as its applicability to both precision ship-relative navigation and mission navigation. Field and flight test results will be discussed as well as future vehicle integration and test plans.

Conference 9457: Biometric and Surveillance Technology for Human and Activity Identification XII

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9457-1, Session 1

Implementation and optimization of a biometric cryptosystem using iris recognition

Charles McGuffey, Chen Liu, Stephanie Schuckers, Clarkson Univ. (United States)

Protecting data is an important part of life in the modern world. The science of protecting data, known as cryptography, makes use of secret keys to encrypt data in a format that is not easily decipherable. However, most modern cryptography systems use passwords to perform user authentication. These passwords are a weak link in the security chain, and are a common point of attack on cryptography schemes. One alternative to password usage is biometrics, e.g., using a person's physical characteristics to verify who the person is and unlock the data correspondingly. This study provides a concrete implementation of one biometric cryptosystem of interest. In addition, hardware acceleration has been performed on the system in order to reduce system runtime and energy usage, which is compared with software-level code optimization. The experiment takes place on a Xilinx Zynq-7000 All Programmable SoC. Software implementation is run on one of the embedded ARM A9 cores while hardware implementation makes use of the programmable logic. This has resulted in an algorithm with strong performance characteristics in both energy usage and runtime.

9457-2, Session 1

Fingerprint + Iris = IrisPrint

Asem A. Othman, Arun A. Ross, Michigan State Univ. (United States)

We consider the problem of generating a biometric image from two different traits. Specifically, we focus on generating an IrisPrint that inherits its structure from a fingerprint image and an iris image. To facilitate this, the continuous phase of the fingerprint image, characterizing its ridge flow, is first extracted. Next, a scheme is used to extract minutiae from an iris image. Finally, an IrisPrint will be created by mixing these components; so the IrisPrint ridge flow is the ridge flow of the fingerprint and the locations of its minutiae are the locations of the iris minutiae. Preliminary experiments on fingerprint and iris datasets suggest that the new biometric image (i.e., IrisPrint) (a) can potentially be used for authentication by an existing fingerprint system, and (b) can potentially conceal the original fingerprint and iris images because they cannot be easily matched with the IrisPrint.

9457-3, Session 1

Identifying Bitcoin users by transaction behavior

John V. Monaco, Pace Univ. (United States)

Digital currencies, such as Bitcoin, offer convenience and security to criminals operating in the black marketplace. Some Bitcoin marketplaces, such as Silk Road, even claim anonymity. This claim contradicts the findings in this work, where long term transactional behavior is used to identify and verify account holders. Transaction timestamps and network properties observed over time contribute to this finding. The timestamp of each transaction is the result of many factors: the desire purchase an item, daily schedule and activities, as well as hardware and network latency. Dynamic network properties of the transaction, such as coin flow and the number of edge outputs and inputs, contribute further to reveal account identity. In this paper, we propose a novel methodology for identifying and verifying Bitcoin users based on the observation of Bitcoin transactions over time. The behavior we attempt to quantify roughly occurs in the social band of Newell's time scale. A subset of the Blockchain 230686 is taken, selecting users that initiated between 100 and 1000 unique transactions per month for at least 6 different months. This dataset shows evidence of being nonrandom and nonlinear, thus a dynamical systems approach is taken. Classification and authentication accuracies are obtained under various representations of the monthly Bitcoin samples: outgoing transactions, as well as both outgoing and incoming transactions are considered, along with the timing and dynamic network properties of transaction sequences. The most appropriate representations of monthly Bitcoin samples are proposed. Results show an inherent lack of anonymity by exploiting patterns in long-term transactional behavior.

9457-4, Session 2

Human actions recognition in confined spaces and under partial observability constraints

Amir Shirkhodaie, Tennessee State Univ. (United States); Alex L. Chan, Shuowen Hu, U.S. Army Research Lab. (United States)

This paper presents an ontology-based framework for human activity recognition based on modeling of motions of partially observable human body parts within confined spaces. Intuitively, a collective understanding of human body part movements can lead to better understanding and representation of any human actions. In this paper, we proposed an ontological approach to analyze in-vehicle human activity recognition via a generative learning scheme, which examines partially observable local and global motion of the human body parts in order to detect and classify human actions. Under this scheme, a fast approach is initially applied to detect local observable motions. Then, appearance-based salient motions are extracted and associated with spatiotemporally tracked human body parts. Through this process, the sparse local and global motions of human body parts are co-registered and fused robustly with the relevant information from local appearance changes. Furthermore, a Hidden Markov Model (HMM), trained with established human activity ontological patterns, is developed to recognize spatiotemporal human activities. The proposed method is evaluated using several datasets and the results are compared against other state-of-the-art methods.

9457-6, Session 2

Human task performance baseline: results from a cross-band facial identification perception study

Kenneth A. Byrd, Hee-Sue Choi, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Cross-band facial recognition is a difficult task, even for the most robust matching algorithms. Inherent factors such as camera effects (blur, noise, and sampling), and variation in pose and illumination, are known to negatively affect algorithm performance. Because cross-band matching algorithms are in the infancy of development, it is currently unclear if their performance is superior to human observers performing this task. In

this paper, we present findings from a pilot study aimed at analyzing the ability of an ensemble of human observers to perform the 1:N cross-band facial identification task on degraded facial images, where the probe and gallery images were captured in different spectral bands (visible, SWIR, MWIR and LWIR). Results from our 11-alternative forced choice perception study indicate that: 1) a group of observers familiar with even a subset of subjects in a gallery set are, on average, able to perform the task with higher probability ($p>0.15$) than a group of observers with no prior exposure, and 2) task performance for both the familiar and unfamiliar groups increased 1.5-3.4% when matching multi-spectral probe images to galleries of 24-bit color facial images vs. 8-bit monochrome facial images. For the SWIR case, however, we observed a 9.1% increase in performance with 24-bit facial images vs. 8-bit facial images. Results from this study can be leveraged for future work directly comparing cross-band matching performance of humans vs. algorithms.

9457-7, Session 3

Rapid-DNA as a new biometric for family relationship verification *(Keynote Presentation)*

Christopher Miles, U.S. Dept. of Homeland Security (United States)

No Abstract Available

9457-8, Session 4

A gallery approach for off-angle iris recognition

Mahmut Karakaya, Rashiduddin Yoldash, Meliksah Univ. (Turkey); Christopher B Boehnen, Oak Ridge National Laboratory (United States)

It has been proven that hamming distance score between frontal and off-angle iris images of same eye differs in iris recognition system. The distinction of hamming distance score is caused by many factors such as image acquisition angle, occlusion, pupil dilation, and limbus impact. In this paper, we first study the effect of the angle variations between iris plane and the image acquisition systems. We present how hamming distance changes for different off-angle iris images even if they are coming from the same iris. We observe that increment in acquisition angle of compared iris images causes the increment in hamming distance. Second, we propose a new technique in off-angle iris recognition system that includes creating a gallery of different off-angle iris images (such as, 0, 10, 20, 30, 40, and 50 degrees) and comparing each probe image with these gallery images. We will show the accuracy of the gallery approach for off-angle iris recognition.

9457-9, Session 4

Neurological disorder identification by eye movement biometric using machine learning schemes

Vivek Srivastava, Rama Univ. (India); Pipin K. Tripathi, Harcourt Butler Technological Institute (India); Vinay K Pathak, HBTI KANPUR (India)

In recent past, many neurological disorders diagnosed with the help of eye movement signals. Such type of disorders is reflected through the abnormalities of eye movements. This is why eye movement signals are being utilized for identification of such brain level abnormalities. The key factor that is associated with such identification is the combined nature of human eye movement plant and brain stem control. For defense personnel, timely identification of neurological disorders plays crucial role in order to prevent the degree of such disorders from mild to severe as they have higher chance for repeated trauma. Further, eye movement biometric features extracted from eye movement signals are being used for such diagnosis due to its intrinsic discrimination properties and associated brain level activity. In this paper, we investigated the mild traumatic brain injury (m-TBI) neurological disorder identification by eye movement biometric through intelligent machine learning schemes. Three different approaches have been involved in intelligent machine learning scheme: first is evolutionary fuzzy clustering, second is supervised neural network and third is the fusion of evolutionary fuzzy clustering with neural network. We assessed the three comparative analyses of intelligent machine learning for m-TBI identification from eye movement signals. Velocity threshold identification algorithm is employed for fixation identification from raw eye movement signals. After that, biometric feature vectors are derived from obtained fixations and saccades. The m-TBI quantitative features (fixation count, fixation duration, vectorial saccade amplitude, fixation quantitative score, simple overshoot, multi-corrected undershoot and the agonist muscle activation-time constant) are generated through achieved biometric features. Based on the threshold, disorder is identified. The results obtained through our experiments over eye movement signals demonstrate the promising outcome for m-TBI diagnosis.

9457-10, Session 4

An indexing method for color iris images

Simona G. Crihalmeanu, Arun A. Ross, Michigan State Univ. (United States)

In this work, we study the possibility of indexing color iris images. In the proposed approach, a clustering scheme on a training set of iris images is used to determine cluster centroids that capture the chromaticity of the iris texture. An iris image is indexed by comparing its pixels against these centroids and determining the dominant clusters - i.e., those clusters to which the majority of its pixels are assigned to. The cluster indices serve as an index code for an input iris image and are used during the search process, when an input probe has to be compared with a gallery of irides. Experiments using multiple color spaces convey the efficacy of the scheme, with hit rates closes to 100% being achieved at low penetration rates.

9457-11, Session 5

Deep learning and face recognition: the state of the art

Stephen Balaban, Lambda Labs (United States)

Deep Neural Networks (DNNs) have established themselves as a dominant technique in machine learning. DNNs have been top performers on a wide variety of tasks including image classification, speech recognition, and face recognition [1–3]. Convolutional Neural Networks (CNNs) have been used in nearly all of the top performing methods on the Labeled Faces in the Wild (LFW) dataset [3–5]. In this talk and accompanying paper, I attempt to provide a review and summary of the deep learning techniques used in the state-of-the-art. In addition, I highlight the need for both larger and more challenging datasets to benchmark these systems.

Despite the ability of DNNs and auto-encoders to perform unsupervised feature learning, modern facial recognition pipelines still require domain specific engineering in the form of re-alignment. For example, in Facebook's recent DeepFace paper, a 3D "frontalization" step lies at the beginning of the pipeline. This step creates a 3D face model for the incoming image and then uses a series of affine transformations of the fiducial points to "frontalize" the image. This step enables the DeepFace system to use a neural network architecture with locally connected layers without weight sharing as opposed to standard convolutional layers [5]. Deep learning techniques combined with large datasets have allowed research groups to surpass human level performance on the LFW dataset [3].

The high accuracy (99.15% face verification accuracy for DeepID2) and

utilization of outside data (millions of images in the case of Facebook's DeepFace) suggest that current face datasets such as LFW may not be challenging enough for current techniques [3]. There exist a variety of organizations with mobile photo sharing applications that would be capable of releasing a very large scale and highly diverse dataset of facial images captured on mobile devices. Such an "ImageNet for Face Recognition" would likely receive a warm welcome from researchers and practitioners alike.

Citations:

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9457-12, Session 5

Computational cameras for iris recognition

Scott McCloskey, Sharath Venkatesha, Honeywell Automation & Control Solutions (United States)

Iris-based biometric identification is increasingly used for facility access and other security applications. Like all methods that exploit visual information, however, iris systems are limited by the quality of captured images. Optical defocus due to a small depth of field (DOF) is one such challenge, as is the acquisition of sharply-focused iris images from subjects in motion. At a high level, there are two complementary approaches to dealing with image quality limitations. One is to make the matching algorithm more robust to image quality loss, through multi-biometric fusion or by extracting features with invariance to blur. A second approach, which we pursue, is using non-traditional cameras to capture iris images which make matching easier in difficult settings.

Traditional imaging is constrained by a number of well-known tradeoffs. In low-light environments - which are common for indoor, uncooperative iris recognition – the well-known photographic tradeoff is between a long-exposure, small-aperture exposure and a short duration exposure with a larger aperture. As illustrated in Figure 1, this amounts to a tradeoff between motion and optical blur due to subject movement and limited depth of field, respectively. Despite the rapid improvement in solid state sensor resolution, this tradeoff will persist due to the limits of the photon conversion process (existing back-illuminated CCDs already have quantum efficiencies above 90%).

Computational cameras are becoming more prevalent, with Lytro's release of a consumer-grade light field camera, and with the increasing adoption of computational photographic techniques (high dynamic range imaging, panoramic stitching, refocusing, etc.) in mobile phone cameras. In this talk, I will describe the performance of two computational photographic techniques for iris recognition: coded exposure and motion invariance. Both combine non-traditional image capture with image post-processing to reduce artifacts arising from motion de-blurring, but differ significantly in important ways that impact the design of iris recognition systems. Our experiments show that, in a real world system where subject velocity is unknown, motion invariance provides the best recognition performance as long as a suitably-chosen Point Spread Function (PSF) is de-convolved.

9457-13, Session 5

Privacy issues related to fingerprint recognition systems

Emanuela Marasco, West Virginia Univ. (United States); Bojan Cukic, The Univ. of North Carolina at Charlotte (United States)

When deploying biometrics for personal recognition, along with security and convenience, comes a concern for information privacy. Information privacy addresses issues related to the use of information pertaining to an individual. Biometrics applications typically require a central database of gallery data containing relevant information about each authorized individual, to guard against multiple enrollment attempts. Such centralized storage causes higher privacy concerns compared to applications in which the individual's data is stored in separate locations, for example, on a card. The constitutional right of privacy affects biometrics used in government mandated applications. An individual who provides a biometrics possesses legal rights; and, the government collecting the biometric is responsible for the acquired data. A common question people ask is: "Can a citizen refuse to provide a biometric identifier?". Identity fraud and terrorism are relevant problems. Biometrics can help to protect against them if used properly. But protections against misuse of biometric data are important as well.

Fingerprint scanners are being used for unlocking the phone (e.g., iPhone 5S) or to make purchases. Risks associated with the possibility of making a person's fingerprint public cause insecurity and distrust. A further application which raises serious questions about privacy is the Mobile Offender Recognition and Information System (MORIS) [3] designed to improve speed and accuracy of police work. MORIS can photograph the face of a person and match it to a database of US criminals without the person being aware of it. This device may potentially become a de-facto surveillance system; thus, many concerns about privacy have risen up. Additionally, the wide use of facial recognition technology, such as on Facebook, is arising privacy concerns. Facial recognition technology can be used without the knowledge or consent of the individual, and anonymity is not guaranteed. For instance, a face photo captured by someone can be used for a match against a database. If an individual goes in a store, video cameras capture the face and enroll him / her in a database that allows for a possible identification in the future. Furthermore, IPhone 6 iris scanners [1] [2] may be used by police as help to identify people or to track criminal suspects. Associated iris-scan databases would raise privacy concerns. Iris recognition technology should be able to address privacy issues because subjects have to agree / participate to enroll images of their irises. However, privacy concerns have prevented the Department of Homeland Security from installing iris scanners at U.S. airports. Also the American Civil Liberties Union considers eye-tracking technology as a privacy threat, when iris scans can be acquired "at-a-distance" and without the subject's knowledge. Finally, advances in human genomic research cause worries about the possibility of inferring medical information from the data stored for identification purpose.

9457-14, Session 5

Anti-spoofing for display and print attacks on palmprint verification systems

Vivek Kanhangad, Shruti Bhilare, Pragalbh Garg, Pranjalya Singh, Narendra S. Chaudhari, Indian Institute of Technology Indore (India)

A number of approaches for personal authentication using palmprint features have been proposed in the literature, majority of which focus on improving the matching performance. However, of late, preventing potential attacks on biometrics system has become a major concern as more and more biometric systems get deployed for wide range of applications. Among various types of attacks, sensor level attack, commonly known as spoof attack, has emerged as the most common attack due to simplicity in its execution, wherein a spoof palmprint is presented in place of a valid biometric to get illegitimate access. In this paper, we present an approach for detection of display and print based spoof attacks on palmprint verification systems. The approach is based on the analysis of acquired hand images for estimating surface reflectance. First and higher order statistical features computed from the distribution of pixel intensities and sub-band wavelet coefficients form the feature set. A trained binary classifier utilizes the discriminating information to determine if the acquired image is of real hand or a fake one. Experiments are performed on a publicly available hand image dataset, containing 1300 images corresponding to 230 subjects. Display and print spoof images used in our experiments were created using real hand images present in this dataset. Experimental results show that the real hand biometrics samples can be substituted by the fake digital or print copies with an alarming spoof acceptance rate as high as 79.8%. Experimental results also show that the proposed spoof detection approach is effective for discriminating between real and fake palmprint images. The proposed approach consistently achieves over 99% average 10-fold cross validation classification accuracy in our experiments. Experimental results presented in this paper suggest that the feature set explored in this work carries adequate information to discriminate between images of real hand and the spoof copies.

9457-16, Session 5

Biometrics and IRB best practices

Christopher B Boehnen, Oak Ridge National Lab. (United States); David Bolme, UT-Battelle (United States); Patrick Flynn, Univ. of Notre Dame (United States)

Biometrics research is inherently tied to the Institutional Review Board (IRB) system for the majority of the world for legal and ethical reasons. IRB approval is required for two reasons. First, because interaction with a human being in a research setting requires an IRB. Second because even if the research does not interact with a person if it uses data that is individually identifiable such as in a face image dataset downloaded from the internet it falls under IRB purview. This paper will discuss the intricacies of IRB best practices within the biometrics community. This is important because human subjects research decisions are made at a local level at which precedent, i.e. the decisions of another IRB board, is not relevant to the decision a specific board makes. In many cases what one board approves would not be approved by another board. This results in significant inconsistencies that is a disadvantage to both the researcher and human subjects. Further, as many IRB boards are unfamiliar with the intricacies of biometrics research they are commonly not qualified as to how best evaluate these protocols. This publication will attempt to define best practice recommendations for performing human subjects research in the biometrics community. However, it is in no way a legal opinion nor does it in any way bind the actions of an IRB. It is merely the opinion of its authors and is presented as such.

9457-17, Session 6

Open-set speaker identification with diverse-duration speech data

Rawande Karadaghi, Heinz Hertlein, Aladdin M. Ariyaeeinia, Univ. of Hertfordshire (United Kingdom)

The concern in this paper is an important category of applications of open-set speaker identification in criminal investigation, which involves operating with short and varied duration speech. Speaker identification is a main subclass of speaker recognition, defined as determining the correct speaker of a given test utterance from a registered population. When the process includes the option of declaring that the test utterance does not belong to any of the registered speakers, then it is specifically referred to as open-set speaker identification (OS-SI). Moreover, if the utterances used for training and testing are not constrained to be of the same linguistic content, the process is called open-set, text-independent speaker identification. This is the most challenging subclass of speaker recognition and has a wide range of applications in such areas as audio indexation, surveillance, and screening.

This study presents investigations into the adverse effects, on the accuracy of open-set speaker identification, of operating with short and varied duration speech. The work is based on the use of the well-established GMM-UBM technique and the i-vector method, which is the state-of-the art approach. The experiments are conducted using a protocol developed for the OS-SI task, based on the NIST speaker recognition evaluation corpus of 2008. In order to closely cover the real-world operating conditions in the considered application area, the study includes experiments with various combinations of training and testing data duration. The experimental results corresponding to these considered scenarios are presented and analysed in terms of the accumulated error rate, which is an error measure designed specifically for the evaluation of OS-SI. In order to facilitate the comparative analysis of the various classification approaches on the basis of the accumulated error rate, a novel score range normalisation technique is introduced in this paper.

The experimental results show that, as expected, with sufficient enrolment and test data, the state-of-the art approaches such as i-vector (with intra-speaker variability compensation) attain a high degree of accuracy in open-set speaker identification and offer significant improvement over more traditional techniques. However, when the reference data is of short and varied duration, the i-vector technique offers only marginal improvement over bilateral GMM-UBM (with score normalisation). Furthermore, if the reference data is too short or if both reference and test data are of varied duration, a significant drop in the OS-SI accuracy is experienced. In this case, there appears to be little difference between the effectiveness achievable by various approaches considered in the study. The paper details the characteristics of the experimental investigations conducted and provides a thorough analysis of the results obtained.

9457-18, Session 6

Multisensor concealed weapon detection using the image fusion approach

Tuzhi Xu, Q. M. Jonathan Wu, Univ. of Windsor (Canada)

In this paper, an effective concealed weapon detection (CWD) algorithm based on image fusion is presented. For CWD application, the fused image is desirable to provide the information on both the concealed weapons from an infrared (IR) or millimeter wave (MMW) sensor image and the appearance of suspects from a visual sensor image. Motivated by the aim of CWD application, special fusion algorithm have been developed. First, the images obtained using different sensors are decomposed into low and high frequency bands using double-density dual-tree complex wavelet transform (DDDTCWT) with sixteen orientations, which is nearly shift-invariance and able to provide directional selectivity. Two different novel decision methods are then introduced referring to the characteristics of the frequency bands and the fusion objective, which significantly improves the image fusion performance for CWD application. An adaptive weighted average strategy based on the local contrast is applied to low frequency band coefficients which reflect the coarser approximation of the original image. The regions having high brightness contain the concealed weapon information in the special sensor image and the appearance information in the visual image and the areas in the other image corresponding to the high bright regions are normally darker. Thus, the local contrast of the corresponding coefficients in the two images is used to decide the weight and the brighter areas are preferable. The high frequency band fusion rule is developed by considering both the texture feature of the human visual system (HVS) and the local energy basis. Noise Visibility Function (NVF) is used as a texture masking to estimate the edge and texture information in the detail coefficients and the local energy is applied to improve the accuracy of the estimation. Finally, the fused image is obtained through the inverse DDDTCWT. Experiments and comparisons demonstrate the robustness and efficiency of the proposed approach and indicate that the proposed fusion rules can be applied to different multiscale transforms and achieve better performance in comparison with existing approaches. Also, the experiments show that the fusion results using the proposed fusion rules on DDDTCWT is superior to other combinations as well as previously proposed approaches.

9457-19, Session 7

Human analytics: challenges and opportunitites

Ioannis A. Kakadiaris, Univ. of Houston (United States)

No Abstract Available

9457-20, Session 7

An automated watchlist identification system for higher security at the border crossings

Ajay Kumar, The Hong Kong Polytechnic Univ. (Hong Kong, China)

Currently available methods of watchlist identification at border-crossings are largely manual and/or operate under constrained settings that require high degree of cooperation from the users. The use of facial masks and makeup, which can also be due to religious belief and/or practices, have posed new challenges on commonly practiced face recognition based watchlist identification. Therefore the screening process at border-crossings is often not accurate and/or is highly time-consuming, especially when a large number of subjects/suspects are to be examined. Therefore there is pressing need to develop an automated system for border-crossings that can examine vital details from around the eyes which are more effectively/conveniently observed under multispectral illumination, identify spoof/fake biometric features, and operate in least constrained manner. This paper details the development of such a unique watchlist identification system (along with the hardware and software) using simultaneous multispectral imaging of passengers passing through the immigration crossings. The developed system can also generate alerts even for the non-watchlist passengers whenever spoof biometric samples, like face masks or iris stamps, are suspected. We detail and describe the development of such system and present performance evaluation from the online images acquired under less-constrained environment. The developed system has a range of applications from immigration crossings using e-channel and passport inspections, to law-enforcement and helpful in providing early warning support for the protection against criminals/terrorist and other human-based threats.

Conference 9458: Cyber Sensing 2015

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9458-1, Session 1

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

9458-2, Session 1

Testing simple deceptive honeypot tools

Aymen Yahyaoui, Tunisian Air Force (Tunisia); Neil C. Rowe, Naval Postgraduate School (United States)

Deception can be a useful defensive technique against cyber-attacks; it has the advantage of unexpectedness to attackers and offers a variety of tactics. Honeypots are a good tool for deception. They act as decoy computers to confuse attackers and exhaust their time and resources. This work tested the effectiveness of two free honeypot tools in real networks by varying their location and virtualization, and the effects of adding more deception to them. We tested a Web honeypot tool, Glastopf (www.glastopf.org), and an SSH honeypot tool, Kippo (code.google.com/p/kippo). We deployed the Web honeypot in both a residential network and our organization's network in the form of several virtual machines; the organization honeypot attracted more attackers starting in the third week. Results also showed that the virtual honeypots received attacks from more unique IP addresses. They also showed that adding deception to the Web honeypot, in the form of additional linked Web pages and interactive features, generated more interest by attackers. For the purpose of comparison, we used examined log files of a legitimate Web-site www.cmand.org. The traffic distributions for the Web honeypot and the legitimate website showed similarities (with much malicious traffic from Brazil), but the SSH honeypot was different (with much malicious traffic from China). Contrary to previous experiments where traffic to static honeypots decreased after the first two weeks, our honeypots received increasing traffic over a period of three months. It appears that both honeypot tools are useful for providing intelligence about cyber-attack methods, and that additional deception is helpful.

9458-3, Session 1

A prototype forensic toolkit for industrial-control-systems incident response

Nickolas B Carr, U.S. Department of Homeland Security (United States); Neil C. Rowe, Naval Postgraduate School (United States)

Industrial control systems (ICSs) are an important part of critical infrastructure in cyberspace. They are especially vulnerable to cyber-attacks because of their legacy hardware and software and the difficulty of changing it. We first survey the history of intrusions into ICSs, the more serious of which involved a continuing adversary presence on an ICS network. We discuss some common vulnerabilities and the categories of possible attacks, noting the frequent use of software written a long time ago. We propose a framework for designing ICS incident response under the constraints that no new software must be required and that interventions cannot impede the continuous processing that is the norm for such systems. We then discuss a prototype toolkit we built using the Windows Management Instrumentation Command-Line (WMIC) tool for host-based analysis and the Bro intrusion-detection software for network-based analysis. Particularly useful techniques we used were learning the historical range of parameters of numeric quantities so as to recognize anomalies, learning the usual addresses of connections to a node, observing Internet addresses (since rarely should external sites connect to an ICS), observing anomalous network protocols such as unencrypted data transfers, observing unusual scheduled tasks, and comparing key files through registry entries and hash values to find possible malicious modifications. We tested our methods on actual data from ICSs including publicly-available data, voluntarily-submitted data, and researcher-provided "advanced persistent threat" data. We found a number of instances of interesting behavior in our experiments. Intrusions were generally easy to see because of the repetitive nature of processing on ICSs, but operators need to be motivated to look.

9458-4, Session 2

Situational consciousness for autonomous cyberspace operations *(Keynote Presentation)*

Steven K. Rogers, Air Force Research Lab. (United States)

No Abstract Available

9458-5, Session 2

Qualia centric hypothetical thinking: applications to vehicle tracking with the fusion of EO and SAR input data sources *(Invited Paper)*

Jonathan L. White, Harding Univ. (United States); Anthony Helmstetter, Arizona State Univ. (United States); Jared L. Culbertson, Igor V. Ternovskiy, Air Force Research Lab. (United States)

In this work, we present a novel improvement to classical vehicle tracking algorithms by implementing a three-tier architecture consisting of a data-centric vehicle tracker paired with a hypothetical thinking layer that is controlled by an overarching goal layer – this models more effectively how a human thinks about and analyzes situations like vehicle tracking. The upper two layers are disassociated from the data itself and instead operate from the idea of qualia in event space. Our proof-of-concept results show how a classical vehicle tracker can be improved by fusing multiple input sources using coincident SAR and EO data paired with a thinking layer that is able to detect, hypothesize, and resolve conflicts.

9458-6, Session 2

Addressing cyber information overload with cognitive modeling constructs

Sandra L. Vaughan, Air Force Institute of Technology (United States) and U.S. Defense Intelligence Agency (United States); Robert F. Mills, Michael R. Grimaila, Gilbert L. Peterson, Air Force Institute of Technology (United States); Steven K. Rogers, Air Force Research Lab. (United States)

Information overload and critical human resource shortages have resulted in unprecedented cyber domain vulnerabilities. Inspired by human intelligence, Artificial Intelligence (AI) and Computational Intelligence (CI) have provided successful engineering solutions in complex domains including cyber. Current AI/CI approaches aggregate large volumes of data to infer the

general from the particular, i.e. Inductive reasoning, and generally cannot infer answers not previously programmed. Whereas humans, rarely able to reason over large volumes of data, have successfully evolved and reached the top of the food chain by inferring situations from partial or even partially incorrect information, i.e. abductive reasoning; generating a hypothetical explanation of the observations.

Humans do not store the details of experiences; we store the significant components of experiences which cognitive researchers have defined as conceptual knowledge, and are represented computationally as prototypical schemas. Conceptual knowledge is brought to bear in human abductive reasoning and situational awareness.

Cognitive research has focused on understanding and predicting human cognitive processes and behavior by developing computational Cognitive Modeling Architectures (CMAs). In this research, conceptual knowledge, abstracted from individual events, will be captured in a prototypical schema and processed in a CMA for improved situational awareness in areas where data overload has become a significant challenge to human operators. The underlying methodology and theories are generalizable to any domain.

9458-7, Session 3

On a simulation study for reliable and secured smart grid communication

Sriharsha Mallapuram, Paul Moulema, Wei Yu, Towson Univ. (United States)

The smart grid is the integration of information and communication technologies and renewable energy resources into the traditional power grid with a vision of providing a reliable, efficient, and environment friendly energy services through two-way energy and information flow between customers and utilities. The smart grid integrates components from both physical world (power grid) and the cyber world (communication network). These two domains are intertwined and designed to work cooperatively with intensive interaction between them. While various technologies and solutions have being proposed to address reliability, cost-efficiency, interoperability, communications challenges of the smart grid, there is a need to study and evaluate these technologies in a safe and reusable environment prior to real-world. Therefore, a software-based co-simulation framework is an adequate environment to conduct such studies. By integrating power grid and communication network within a single unified simulation framework, the co-simulation takes into account the hybrid and heterogeneous nature of smart grid and allows evaluating the system as a whole and studying mutual impacts and dependencies between the cyber world and the physical world.

In this paper, we design and develop a co-simulation framework that integrates two independent simulators: MATLAB for power systems distribution and NS-2 for the communication network. To achieve high level of accuracy, our developed co-simulation framework integrates synchronization mechanisms to address the disparity between a continuous time-based simulator (power grid) and a discrete event-based simulator (communication network simulator). Because the smart grid is an energy-based critical infrastructure, the resilience of the smart grid is critical. We then consider two groups of co-simulation scenarios to evaluate the resilience of the smart grid against failures and attacks. The first group involves the simulations of faults and failures in the physical domain (e.g. transmission lines and power generation failures) whereas the second group focuses on the simulations of cyber-attacks that affect network transmission delay, packet delivery, and power grid operations.

9458-8, Session 3

Risk assessment by dynamic representation of vulnerability, exploitation, and impact

Hasan Cam, U.S. Army Research Lab. (United States)

Assessing and quantifying cyber risk accurately in real-time is essential to providing security and mission assurance in any system and network. This paper presents a modeling and dynamic analysis approach to assessing cyber risk of a network in real-time by representing dynamically its vulnerabilities, exploitations, and impact using integrated Bayesian network, Markov and state-space models. Given the set of vulnerabilities detected by a vulnerability scanner in a network, this paper addresses how its risk can be assessed by estimating in real-time the exploit likelihood and impact of vulnerability exploitation on the network, based on real-time observations and measurements over the network. The dynamic representation of the network in terms of its vulnerabilities, sensor measurements, and observations is built dynamically using the integrated Bayesian network, Markov and state-space models. The transition rates of outgoing and incoming links of states in hidden Markov models are used in determining exploit likelihood and impact of attacks, while emission rates help determine the attack states of vulnerabilities. State-space model and Kalman filter are employed to estimate the range of changes in state variables. Simulations are conducted for performance analysis.

9458-9, Session 3

ASN Reputation System Model

Steve Hutchinson, ICF International (United States); Robert F. Erbacher, U.S. Army Research Lab. (United States)

All traffic on the Internet, indeed every packet, is routed over the multiple links from source to destination via the Boundary Gateway Protocol. This routing protocol uses the autonomous system number (ASN) of the destination to select the 'best' communications link for the next hop, between routers. In intelligence gathering for cyber defense, we frequently need to determine the actual source of suspicious traffic. Unfortunately, the readily observable features of traffic can easily be spoofed, or are highly variable, so as to be useless in source attribution. An organization, company, group, is assigned an (usually one) ASN that specifically labels one or more ranges of IP addresses in that organization's network, thus the ASN is a long-term stable attribute that links all disparate IP address ranges of that organization's network. This paper describes the results of analysis of 7-years of actual malware incident reports as documented by a cyber defense operation. A reputation system and model for suspicious ASNs was developed, and evaluated on a set of recent reports to show the strength of correlation between current and past hostile IP addresses, linked by a common ASN. Lastly, we propose an IP-to-ASN cache model of past hostile ASNs with associated IP ranges for use in predicting the maliciousness of an observed IP address, linked with a known-hostile, or 'tainted' ASN.

9458-10, Session 3

CyberSecurity for aerospace autonomous systems

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

High profile breaches have occurred across all types of information systems: from business systems to systems that manage and support guidance, navigation and control. One area where these attacks are, perhaps, among the most problematic is autonomous control systems. Unlike manual control approaches, where typical verification and non-repudiation techniques can be used to verify that the two communicating parties are who they claim and transmissions have not been altered in route, autonomous systems present a distinct challenge. An autonomous system can, prospectively, be compromised by attacks against the AI (which seek to control it, overwhelm it or otherwise) as well as attacks against the supporting systems which the AI relies upon.

This paper considers the aerospace information system with a particular focus on elements that interact with autonomous control systems (e.g., onboard UAVs). It discusses the trust that is placed in the autonomous systems and supporting systems (such as navigational aids) and how this trust can be validated and if it is well placed. It considers technologies that would support reducing the reliance of the next generation of autonomous control software on these external information suppliers and validation techniques that could be used to determine when to transition from the less computationally expensive (and prospectively more accurate) external positioning technologies to other positioning systems. It also discusses approaches to remotely detect the compromise of UAVs, without relying on the onboard software (on a potentially compromised system) as part of the process and how different levels of autonomy (task-based, goal-based, mission-based) impact this remote characterization. The paper concludes with a discussion of the impact of information warfare on autonomous systems and their efficacy and ethical questions regarding their deployment when their security may be questionable.

9458-11, Session 3

Cybercrime and prospect theory: Considerations for policy efforts and the framing of 'cyber warfare'

Wesley Beaver, Oxford Internet Institute (United Kingdom)

No Abstract Available

9458-12, Session 4

Is cyber warfare threat or advantage for air operations ?

Harun R. Altun, Fatih Buyruk, Ferhat Pinar, Turkish Air War College (Turkey)

In the age of modern warfare, the first and second world wars in the 19th century have direct effects on scientific studies. Scientific studies in the military field has caused ease or difficulties in human life. The weapons used in military operations has changed and developed. New equipments were technologically. Therefore, advances in technology have been very effective in military equipments. Rifles, tanks, planes, ships, helicopters began to be technology based. Emerging technology with air tools, weapons and platforms has changed and developed. Air weapons used in operations and platforms are known to be in the advanced level of addiction to technology. Therefore the increased dependency of cyber environment. In 21st century Cyberspace has been considered as the fifth operations environment after land, sea, air and space. Equipments used in air operations, have evolved by means of technology. In this way, rapid response, high precision, low collateral damage and minimum human loss standards has been improved. However, the development of cyberspace has driven a great effect on technology-based weapons systems. As the dependence of weapons systems on technology has increased, dependence on cyber environment increased accordingly. In recent air campaigns, cyber operations has also taken part in the theater. Cyber operations used in the air strikes have led to different results. In the future, it is assessed that the use of cyber warfare will increase in air operations. In this study cyber operation strategies in air campaigns was analyzed in case studies. Cyber warfare is assessed to be the indispensible part of future air and space campaigns.

9458-13, Session 4

Turkey's cyber security perception and the portion of cyber security in national defence

Mahmut Tükenmez, Turkish Air Force Academy (Turkey)

Technology is constantly progressing and it has begun to impact our daily lives to an alarming extent. Internet passed beyond being a facility tool and began an important medium that is actually necessary. Thus, Internet and our daily lives integrated and imperil our personal information, of equal degree. From databases and private information that stored in governmental institutions, to power plants, waterworks, communications networks and navigation systems; many governmental institutions and services are in danger now. Superfluity of threats, dangers and consequences, all became a non-ignorable reality. Adding this reality the data transfer speed, it will come into light that building effective and strong defence systems, creating an awareness and consciousness on the matter are of great importance. Although it is a relatively new field, there are excess studies and wide range of content on the subject. Setting out all evidences, a final assessment that show the significance of cyber security for national security has been made in this study. Suggestions on the precautions have also been presented in all individual, institutional and national level

9458-14, Session 4

Network systems security analysis

Ismail Yilmaz, Turkish Air Force Academy (Turkey)

Network Systems Security Analysis has utmost importance in today's world. Many companies, like banks which give priority to data management, test their own data security systems with "Penetration Tests" by time to time. In this context, companies must also test their own network/server systems and take precautions, as the data security draws attention.Based on this idea, the study cyber-attacks are researched throughoutly and Penetration Test technics are examined. With these information on, classification is made for the cyber-attacks and later network systems' security is tested systematically. After the testing period, all data is reported and filed for future reference.

Consequently, it is found out that human beings are the weakest circle of the chain and simple mistakes may unintentionally cause huge problems. Thus, it is clear that some precautions must be taken to avoid such threats like updating the security software.

9458-15, Session 4

Efficient non-resonant absorption of electromagnetic radiation in thin cylindrical targets: experimental demonstration

Andrey Akhmeteli, LTASolid Inc. (United States); Nikolay G. Kokodiy, Boris V. Safronov, Valeriy P. Balkashin, Ivan A. 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 and more) 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 shortwavelength 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% vs. theoretical prediction of 12%) 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. These results can be greatly improved via optimization of the reflector shape. For the longitudinal geometry, experiments provide a confirmation of significant absorption (20-25% vs. theoretical prediction of 40%) of the power of a wide CO_2 laser beam propagating along a thin wire (the diameter of the wire is two orders of magnitude less than the beam waist width).

9458-16, Session 4

Cyber warfare and electronic warfare integration in the operational environment of the future: Cyber Electronic Warfare

Osman Askin, Riza Irmak, Mustafa Avsever, Turkish War Colleges, Turkish Naval War College (Turkey)

For the states with advanced technology, effective use of electronic warfare and cyber warfare will be the main determining factor of winning a war in the future's operational environment. The developed states will be able to finalize the struggles they have entered with a minimum of human casualties and minimum cost thanks to high-tech. Considering the increasing number of world economic problems, the development of human rights and humanitarian law it is easy to understand the importance of minimum cost and minimum loss of human. In this paper, cyber warfare and electronic warfare concepts are examined in conjunction with the historical development and the relationship between them is explained. Finally, assessments were carried out about the use of cyber electronic warfare in the coming years.

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9459-1, Session 1

An overview of underwater blue-green optical communications *(Invited Paper)*

Greg Mooradian, Mooradian & Associates, Inc. (United States); Michael Lovern, Space and Naval Warfare Systems Ctr. Pacific (United States)

Energy in the blue-green spectrum is the only electro-magnetic radiation which can transfer information at operationally significant data rates to useful ranges through seawater. In addition to fundamental propagation physics, the lack of stealth and the susceptibility to jamming also impacts the viability of both acoustic and electro-magnetic communications systems.

Underwater Blue-Green Optical Communications is a "game-changer" in connecting a variety of undersea networks where applications include both all-through-water (ATW) and underwater through the air-water-interface (AWI) to above water platforms (especially in an RF denied environment). In order to be viable, the latter requires propagation through the dynamically variable multiple scattering/absorption environments of seawater, fog, rain and clouds, all while operating in full sunlight. This represents a very challenging propagation channel in optical communications.

The overall objective of this paper is to not only review what has been done in the past, but also address both the scope of performance that is possible (e.g., data rate and range), as well as address relevant engineering considerations (e.g., size, weight, and power) to begin predicting capabilities for a variety of innovative architectures that support critical undersea applications. This paper will provide an understanding of the fundamental phenomenology and system architecture issues attendant to making a practical/viable underwater blue-green optical communications system.

9459-2, Session 1

Common underwater free space optical (UFSO) communications architectures in support of both defense and oil and gas applications

Greg Mooradian, Mooradian & Associates, Inc. (United States) and Leidos (United States); Dean Richter, Sonalysts, Inc. (United States); Susan Harris, Leidos (United States); Stephen Szender, Liedos, Inc. (United States)

In the past, Optical Laser Communications (OLC) has been focused on Defense applications for the U.S. Navy. However, OLC is now finding critical applications in support of the Oil and Gas (O&G) industry. While Optical Laser Communications (OLC) includes both all-through-water (ATW) as well as through the air-water interface (AWI) applications, O&G is focused nearly exclusively on ATW architectures.

Four fundamental architectures support the connectivity requirements for the Subsea O&G Industry. These architectures range from (1) low-to-moderately high data rates (e.g., 10 Kbps to 100s of Mbps) between fixed terminals at very short ranges (effectively "subsea wireless connectors"); to (2) data transfer between mobile undersea platforms (e.g., ROVs and AUVs) and fixed terminals at data rates up to 10 Mbps at ranges of 100 m to 250 m with very large coverage envelopes of ±30° to greater than hemispherical; to (3) data exfiltration by AUVs from 100s of seismic sensors deployed on the sea floor (e.g., the "fly-by" CONOPS exfiltrating ≥ 15 GB of data from each sensor at transfer rates of 100s of Mbps); to (4) O&G pipeline monitoring and data access of multiple access nodes using AUVs at long standoff ranges (e.g., up to data transfer rates 10 Mbps at up to ranges of 150 m).

This paper intends to not only show what is the "world of the possible" for these four O&G architectures, but also how these four commercial architectures map into defense applications.

9459-3, Session 1

High bandwidth underwater optical communications: overview and practical applications

Norman E. Farr, Woods Hole Oceanographic Institution (United States)

The optical communications group at Woods Hole Oceanographic Institution (WHOI) has demonstrated high-bandwidth underwater wireless communication for the purposes of video transmission, data harvesting, and vehicle control. The optical communications group, in concert with WHOI's Deep Submergence Laboratory and Sonardyne International, has demonstrated an untethered, remotely controlled vehicle performing manipulation tasks at ranges up to 100 meters. A high ambient light optical system has been used to perform bi-directional video transmission and vehicle control at shorter ranges. A data harvesting operation has successfully recovered 0.25GB of data from a seafloor observatory in 2,500 meters of water using a very modest "ship of opportunity" and a lowered communications module. Current development work has focused on increasing both data rates and ambient light tolerance. The range of the high-bandwidth optical link is, in most cases, complemented by long-range acoustic communications. These developments will be presented along with other demonstrated applications made possible by long-range, high-bandwidth optical communications.

9459-4, Session 1

Spatial multiplexing for blue lasers for undersea communications

Joshua Baghdady, Matthew Byrd, Clemson Univ. (United States); Wenzhe Li, Ctr. for Optical Materials Science + Engineering Technologies (United States); Kaitlyn Morgan, Aaron J. Pung, Eric G. Johnson, Clemson Univ. (United States)

Space Division Multiplexing of optical beams has recently been demonstrated for improving the bandwidth of optical communication links. This paper will explore the use of space division multiplexing utilizing blue lasers for potential undersea applications. Experimental results will be shown for optical vortices utilizing a range of charge numbers corresponding to various Orbital Angular Momentum states.

9459-5, Session 1

High-speed blue-light free space optical receiver

Susan Harris, Mark Krepel, Leidos (United States); Greg Mooradian, Mooradian & Associates, Inc. (United States) and Leidos (United States)

High Speed Underwater Optical Laser Communications are currently limited by the availability of high speed receivers. Leidos, under contract to ONR, is developing a high-speed optical receiver that significantly increases single channel data rates for free-space underwater optical data transmission.

Previous efforts have successfully communicated data at rates up to 1.2 gigabits per second and have used photomultiplier tubes (PMT) as the optical receiver element. PMT detectors are limited to line rates less than 2 gigabits per second.

The work described in this paper is focused on the investigations of optical receivers that would support data rates greater than 2 gigabits per second with expanded working optical power dynamic range. The detector selected for this effort, an avalanche photo diode, operates adequately to support a data channel at line rates of 4 gigabits per second. The avalanche photo diodes tested in this effort have active area diameters less than 0.25 millimeters. The small sampling area requires incoming optical beam collimation and concentration to operate at ranges greater than a few meters. The expected field of view of the receiver using tradition refractive optics is less than 1 degree. This narrow field of view is not compatible with underwater optical receivers that depend on the ability to accept light subjected to small angle scattering. To overcome this limitation, this effort includes development and test of a volume holographic array optical concentrator to capture a 5-degree field of view, and concentrate it onto the active area of the photo diode.

9459-6, Session 1

Airborne relay connectivity through air/ice/water interface comm (ARCTIComm) high data rate through-ice optical communication system

Dean Richter, Sonalysts, Inc. (United States); Greg Mooradian, Mooradian & Associates, Inc. (United States); Susan Harris, Stephen Szender, Leidos (United States)

The Airborne Relay Connectivity Through air/ice/water Interface Comm (ARCTIComm) Optical Laser Communications (OLC) system will support the real-time exchange and exfiltration of information collected under the polar ice, enabling the networking of data from fixed distributed sensors and mobile platforms (e.g., both above water aircraft as well as underwater platforms) and the aggregation of their data for enhanced analysis and interpretation. ARCTIComm becomes an Arctic “information enabler;” dramatically increasing Arctic situational awareness for both commercial and national security applications.

Transferring information through seawater, ice and snow is fundamentally limited by physics. RF and acoustics all fill a niche in enabling the “networking” of underwater terminals and platform;, however blue-green OLC provides the only technology capable of truly connecting the undersea environment (even through polar ice and snow) at the data rates required.

Defined by the geometry of the platforms/terminals, the Employment Concept for ARCTIComm results in two system implementations: (1) ARCTIComm two-way data transfer directly between underwater assets and airborne platforms (manned aircraft or UAVs) at 100s of Kbps to 30 Mbps, and (2) two-way data transfer between underwater assets and small/low-cost/long-endurance Surface Artic Relay Terminals (SARTs) at 36 – 60 Mbps. The SARTs then connect to the outside world through low power RF links (e.g. line-of-sight (LOS) RF through a relay aircraft or satellite). Under-ice sensors and platforms (e.g., UUVs or submarines) will then have the ability to rendezvous with pre-deployed SART gateway terminals and transmit data via above-the-ice RF links.

9459-7, Session 2

Underwater-detector array for laser beam diagnostics

Shachak Pe’eri, Firat Eren, The Univ. of New Hampshire (United States); Jack L. Riley, National Oceanic and Atmospheric Administration (United States); May-Win Thein, Yuri Rzhanov, Matthew Birkebak, The Univ. of New Hampshire (United States)

Underwater optical propagation is used in many marine applications, such as airborne lidar bathymetry (ALB), subsurface navigation and communication. Previous studies on performance evaluation of underwater applications involving laser propagation have been heavily dependent on simulations that provide an approximation to the direct measurement of the laser beam. Results from light propagation simulations that attempt to include complex effects such as multiple scattering may differ significantly. In this paper, we present two experimental designs of underwater detectors using a 6-by-6 array of photodiodes. The design of the array is based on considerations of the performance of the photodiodes and potential noise sources within the associated hardware. Performance evaluation tests for the two array detectors are conducted in the Ocean Engineering Tank Facilities at the University of New Hampshire. The study presented in this paper also includes geometric beam path diagnostics for a green (532 nm) laser source. The test measurements take into account the source light field and explore the effects of variable environmental conditions in water column scattering (turbidity) and seafloor reflectance.

9459-8, Session 2

Chaotic lidar for underwater channel identification

Luke K. Rumbaugh, David W. Illig, William D. Jemison, Clarkson Univ. (United States)

The impulse response/transfer function of the underwater channel is characterized using a 532 nm chaotic lidar transmitter.

The transmitter is based on a 1064 nm fiber ring laser which generates quasi-CW chaotic intensity modulation with ~1 GHz bandwidth at baseband. Two fiber amplifier stages and a frequency doubling periodically poled crystal are used to generate sufficient power at 532 nm for transmission underwater.

To obtain the impulse response of the underwater channel, the lidar beam is split into a reference and a probe signal. The probe signal is sent through the water, and on its return it is detected by a high-speed photomultiplier tube and then digitized. The reference signal is likewise detected by a high-speed photodetector and digitized, and the two signals are cross-correlated. The resulting impulse response indicates reflective targets and scattering elements in the underwater scene.

The wide bandwidth of the transmitter, and the high speed components used for the receiver, allow effective characterization of the channel from DC to 1 GHz. Characterizations are shown for ranging scenarios with multiple targets and heavy scattering. The effect of frequency domain selection are explored, indicating the usefulness of impulse response/transfer function measurements for scatter suppression.

9459-9, Session 2

Experimental validation of a Monte Carlo model for determining the temporal response of the underwater optical communications channel

Alan Laux, Brandon Cochenour, Naval Air Warfare Ctr. Aircraft Div. (United States)

In turbid environments, underwater optical communications channel are “dispersion limited” due to the scattering of light by small particles. This scattering causes two forms of dispersion: spatial and temporal. Spatial dispersion, or beam spread, occurs as the initial transmitted photon paths are altered due to interaction with the particles. At the receiver, the path length differences that arise from spatial dispersion can result in a form of intersymbol-interference. This temporal dispersion ultimately limits link bandwidth and range.

Attempts to model temporal dispersion typically fall under two categories. The first aims to find an analytical solution to the Radiative Transfer Function (RTE). In order to find a tractable solution though, one is often forced to make a series of simplifying assumptions. The benefits of these simplifying assumptions however tend to be negated by the reduced fidelity in the temporal components they aim to describe. One the other hand numerical techniques, such as Monte Carlo models, provide better accuracy but require significantly more processing time and power. Regardless of the method chosen, few of the models reported in the literature are validated against experimental data. This is particularly true in the cases of high speed (approaching 1 GHz) and high scattering environments where temporal dispersion is expected to be highly sensitive to small changes in environment or link geometry. The reason for the lack of experimental measurements is due in part to the technological challenges placed on the source and receiver hardware needed to make such high speed measurements with sufficient sensitivity in the blue/green portion of the spectrum. Fortunately the authors have previously reported on a high-sensitivity/high-dynamic range measurement technique that has begun to provide some of the necessary experimental data which can be used for model validation. [1]

In this work, we report on our own Monte Carlo model for determining the frequency response of the underwater optical communications channel, and compare results against these new experimental data sets. Specifically, we evaluate the numerical model to the experimental data as a function of frequency (< 1 GHz), turbidity (<20 attenuation lengths), particle scattering function, transmitter/receiver alignment, and receiver FOV.

[1] B. Cochenour, L. Mullen, and J. Muth, "Temporal response of the underwater optical channel for high-bandwidth wireless laser communications," IEEE Journal of Oceanic Engineering, vol 38, no 4, Oct 2013.

9459-12, Session 3

FMCW optical ranging technique in turbid waters

David W. Illig, Clarkson Univ. (United States); Alan Laux, Robert W. Lee, Naval Air Systems Command (United States); William D. Jemison, Clarkson Univ. (United States); Linda J. Mullen, Naval Air Systems Command (United States)

Conventional methods for detecting the range to an underwater object involve sending and receiving an acoustic signal. Under certain conditions, the range resolution and accuracy of acoustic systems may be limited. Laser-based range finders offer the possibility for high-precision range accuracy in the underwater environment. However, these systems experience an exponential loss due to scattering and absorption of photons. Absorption reduces received signal power, while scattering produces a "clutter" signal. Optical modulation techniques have been shown to provide accurate range information in a variety of underwater environments.

The performance of a frequency-modulated continuous-wave (FMCW) hybrid lidar-radar system will be presented in the context of an underwater ranging application. In this technique, the radar frequency is modulated with a linear ramp over a fixed bandwidth for a fixed duration. The transmitted signal is mixed with a reference copy to obtain a beat frequency, indicating the distance to the desired object. This work will use a short ramp duration and a wide bandwidth to achieve large unambiguous range and high resolution, respectively. The frequency band will be selected to be high enough to take advantage of channel physics so that the effects of scattering can be reduced. The FMCW equations will be derived for turbid waters, a highly scattering environment. The derived theory and simulated predictions indicate that FMCW can detect both the desired object and the volumetric center of the backscatter "clutter" signal. Results from laboratory experiments will be presented and compared to both model predictions and prior work with different ranging techniques.

9459-13, Session 3

Pulse compression techniques to improve modulated pulsed laser line scan systems

Robert W. Lee, Naval Air Systems Command (United States) and Univ. of Maryland (United States); Justin Nash, Brandon Cochenour, Linda J. Mullen, Naval Air Systems Command (United States)

A modulated pulse laser imaging system has been developed which utilizes coded/chirped RF modulation to mitigate the adverse effects of optical scattering in degraded visual underwater environments. Current laser imaging techniques employ either short pulses or single frequency modulated pulses to obtain both intensity and range images. Systems using short pulses have high range resolution but are susceptible to scattering due to the wide bandwidth nature of the pulse. Range gating can be used to limit the effects of backscatter, but this can lead to blind spots in the range image. Modulated pulse systems can suppress the contribution from scattered light in generated imagery without gating the receiver. However, the use of narrow-band, single tone modulation, results in limited range resolution. Targets can be small and camouflaged within the background. This drives the need for systems which have high range resolution while still suppressing the effects of scattering caused by the environment. Coded/chirped modulated pulses enable the use of radar pulse compression techniques to substantially increase range resolution while also providing a way to discriminate the object of interest from the light scattered due to the environment. Linearly frequency chirped waveforms and phase shift keyed barker codes were experimentally investigated to determine the effects that pulse compression would have on intensity/range images. Different processing algorithms for coded/chirped pulses will be explored, and the results from laboratory experiments will be presented and compared to model predictions.

9459-14, Session 3

DCS versus DCS: evaluation of different signal models for the underwater compressive line sensing imaging system

Bing Ouyang, Harbor Branch Oceanographic Institute (United States); Weilin W. Hou, U.S. Naval Research Lab. (United States); Frank M. Caimi, Fraser R. Dalgleish, Anni K. Vuorenkoski, Harbor Branch Oceanographic Institute (United States); Cuiling Gong, Texas Christian Univ. (United States)

In recent years, a type of compressive sensing (CS) based underwater imaging system concept – Compressive Line Sensing (CLS) imaging system was proposed [1]. One of the main objectives of this concept is to enable resource efficient system that is optimum for power-constraint unmanned platforms such as UUVs/AUVs. In the CLS system, each line segment is sensed independently; when reconstructing the signal, the correlation among the adjacent lines is exploited to achieve high fidelity using a reduced number of measurements of each line. In the current implementation, the distributed compressing sensing model [3] is adopted to jointly reconstruct a group of lines. In distributed compressing sensing joint sparsity model-1, each line (i.e. source) consists of a common component shared with all other sources and a unique component. An l1-norm minimization solver is then adopted to recover these lines.

Lately a new CS signal model – dynamic compressive sensing [2] was proposed to recover correlated, time-varying signals using non-adaptive, linear measurements from a Bayesian perspective. The amplitude and support correlation structure is captured through a computational efficient approximate message passing scheme. In this regard, the CLS problem fits well with the scope of the dynamic compressive sensing model. One of the aspects of the dynamic compressive sensing motivates the attempt of solving CLS problem with this framework is its ability to learn model parameters adaptively from the data. In the distributed compressive sensing model, model parameter adaption is not considered.

This paper investigates these difference models in solving the CLS problem through the comparison of their performance in a series of simulations and against different experimental datasets.

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9459-15, Session 3

Semi-empirical inversion technique for retrieval of quantitative attenuation profiles with underwater scanning LIDAR systems

Anni K. Vuorenkoski, Fraser R. Dalgleish, Harbor Branch Oceanographic Institute (United States); Michael S. Twardowski, WET Labs., Inc. (United States); Bing Ouyang, Harbor Branch Oceanographic Institute (United States); Charles C. Trees, STO-CMRE (Italy)

No Abstract Available

9459-16, Session 4

Analysis of polarimetric image by full stokes vector imaging camera for retrieval of target polarization in underwater environment

Yalong Gu, Carlos Carrizo, Ahmed El-Habashi, Alexander Gilerson, The City College of New York (United States)

The absorption and scattering of light in aquatic environments can significantly degrade the image quality. However, polarization provides another channel for target imaging in turbid waters. Some animals in the ocean have partially polarized surfaces which could be advantageous for camouflage or conversely for increased conspicuousness. Polarimetric imaging of such targets in various underwater conditions as well as the retrieval of target polarization characteristics from polarimetric imaging is of significant scientific and technological interest. Recently developed full Stokes vector imaging cameras can record the polarization pattern of a scene. It contains rich information of the targets which strongly depends on the inherent optical properties of the water. Generally, the formed polarimetric image results from a complex imaging process including underwater radiance from the Sun, underwater light propagation, light reflection on target surface and light detection by underwater imaging optics. However, our Monte Carlo simulation of underwater light propagation shows that the forward scattering of light can be often neglected.
With a simplified underwater polarimetric imaging model, we analyze the polarimetric images of a manmade underwater target with known polarization properties which were acquired by a full Stokes vector imaging camera in a recent field trip. Decrease of polarization induced by the camera's numerical aperture is observed and evaluated. With the knowledge acquired in the analysis of such a forward polarimetric imaging process, we also explore algorithm to extract the inherent optical properties of the water and finally to retrieve the polarization characteristics of the target.

9459-17, Session 4

The influence of the choice of the phase function on imaging under water

Katrin Braesicke, Endre Repasi, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

There is a large diversity of phase functions for the computer simulation of light under water. We study the influence of these phase functions on the simulation of the resulting image of a target. For these simulations we are only interested in those parts of the light that reach the camera position. Therefor we investigate the influence of the phase function on the image.

We use a Monte Carlo Simulator with several Fournier-Forand, Henyey-Greenstein phase functions. The resulting signals at the receiver of these simulations are compared to a simulation with a Petzold function that is based on measurements of the phase function.

9459-18, Session 4

A controlled laboratory environment to study EO signal degradation due to underwater turbulence

Silvia C. Matt, Weilin W. Hou, Wesley Goode, Andrey V. Kanaev, Sergio R. Restaino, U.S. Naval Research Lab. (United States)

Temperature microstructure in the ocean can lead to localized changes in the index of refraction and can distort underwater electro-optical (EO) signal transmission. A similar phenomenon is well-known from atmospheric optics and generally referred to as "optical turbulence". Though turbulent fluctuations in the ocean distort EO signal transmission and can impact various underwater applications, from diver visibility to active and passive remote sensing, there have been few studies investigating the subject.
To provide a test bed for the study of impacts from turbulent flows on underwater EO signal transmission, and to examine and mitigate turbulence effects, we set up a laboratory turbulence environment allowing the variation of turbulence intensity. Convective turbulence is generated in a large Rayleigh-Bénard tank and the turbulent flow is quantified using high-resolution Acoustic Doppler Velocimeter profilers and fast thermistor probes. The turbulence measurements are complemented by computational fluid dynamics simulations of convective turbulence emulating the tank environment. These numerical simulations supplement the sparse laboratory measurements. The numerical data compared well to the laboratory data and both conformed to the Kolmogorov spectrum of turbulence and the Batchelor spectrum of temperature fluctuations. The controlled turbulence environment can be used to assess optical image degradation in the tank in relation to turbulence intensity, as well as to apply adaptive optics techniques. This innovative approach that combines optical techniques, turbulence measurements and numerical simulations can help understand how to mitigate the effects of turbulence impacts on underwater optical signal transmission, as well as advance optical techniques to probe oceanic processes.

9459-19, Session 4

A miniature fiber-optic sensor for high-resolution and high-speed temperature and flow sensing in ocean environment

Ming Han, Univ. of Nebraska-Lincoln (United States); Weilin W. Hou, U.S. Naval Research Lab. (United States); Guigen Liu, Univ. of Nebraska-Lincoln (United States)

In oceanography, the underwater thermal structures are critical for analyzing the energy events, monitoring material transfer, transmitting optical signals,

etc. In this paper, we present an optical fiber sensor for the high-resolution and high-speed temperature profiling. The developed sensor consists of a thin piece of silicon wafer which forms a Fabry-Perot interferometer (FPI) on the end of fiber. Due to the unique properties of silicon, such as large thermal diffusivity, notable thermo-optic effects and thermal expansion coefficients of silicon, the proposed sensor exhibits excellent sensitivity and fast response to temperature variation. The small mass of the tiny probe also contributes to a fast response due to the large surface-to-volume ratio. The high reflective index at infrared wavelength range and surface flatness of silicon endow the FPI a spectrum with high visibilities, leading to a superior temperature resolution along with a new data processing developed by us. Experimental results indicate that the fiber-optic temperature sensor can achieve a temperature resolution ~0.001 degree Celsius with a sampling frequency higher than 500 Hz. In addition, the miniature footprint of the senor provide high spatial resolutions. By heating the silicon film using a visible light which is well separated from the signals in infrared range, we will demonstrate that the proposed sensor can also be used as a water flow sensor.

9459-11, Session 5

Detecting oil on water using polarimetric imaging

Amber Iler, Patrick Hamilton, Integrity Applications, Inc. (United States)

Integrity Applications Incorporated (IAI) collected electro-optical polarimetric imagery (PI) to evaluate its effectiveness for detecting oil on water. Data was gathered at multiple sun angles for vegetable oil and crude oil to demonstrate PI sensitivity to different liquids and collection geometries. Unique signatures for oil relative to water were observed. Both oils consistently displayed higher degree of linear polarization (DOLP) values than water, which was expected based on the lower index of refraction of water (1.33) relative to vegetable oil and crude oil (1.47 and 1.47-1.57, respectively). The strength of the polarimetric signatures was found to vary as a function of collection angle relative to the sun, with peak linear polarizations ranging from 40-70% for crude oil and 20-50% for vegetable oil. IAI found that independently-scaled DOLP was particularly useful for discriminating these liquids, because it demonstrated the least sensitivity to collection angle, compared to other PI products. Specifically, the DOLP signature of vegetable oil was approximately 20% lower than for crude oil, regardless of collection angle. This finding is consistent with the lower index of refraction values for vegetable oil compared to crude. Based on the promising results presented here, IAI recommends further testing and development of PI for oceanic remote sensing applications such as oil spill/leak detection and for supporting oil cleanup efforts. With additional work, PI may also be applicable to other oceanic environmental issues such as detection of agricultural runoff or effluent from industrial facilities or watercraft.

9459-20, Session 5

An expansion of glider observation strategies to systematically transmit and analyze preferred waypoints of underwater gliders

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The Glider Observation STrategies (GOST) system provides real-time assistance to ocean glider pilots by suggesting preferred ocean glider waypoints based on relations among glider trajectories and on ocean forecasts and their uncertainties. Using existing operational regional Navy Coastal Ocean Model (NCOM) output, demonstrations of glider waypoint calculation are ongoing in Navy operational areas. After the ocean forecast models and GOST components run at the Navy DoD Supercomputing Resource Center (Navy DSRC), GOST-suggested glider paths are transferred to the Glider Operations Center (GOC). The glider pilots at the GOC import this information into their Unmanned Systems Interface (USI), developed at the University of Washington, Applied Physics Laboratory (APL-UW) to evaluate the suggested glider paths, make adjustments, and update waypoints for the gliders. The waypoints being sent are visualized and analyzed using graphic capabilities to convey guidance uncertainty developed under a grant to the University of New Orleans (UNO) and added under the Environmental Measurements Path Planner (EMPath) system within GOST. USI forwards automatic messages from the gliders with recent glider location, speed, and depth to GOST for the next cycle. Over the course of these demonstrations, capabilities were added or modified including use of initial glider bearing, refinement of glider turn frequency, correction of glider speed, and introduction of glider rendezvous locations. Automation has been added with help from the modeling group at the Naval Oceanographic Office (NAVOCEANO). GOST supports NAVOCEANO's ongoing efforts to direct and recover gliders, to safely navigate in changing ocean conditions, and to provide feedback to improve ocean model prediction.

9459-21, Session 5

Are the satellite-observed narrow, streaky chlorophyll filaments locally intensified by the submesoscale processes?

Igor Shulman, Bradley Penta, James G. Richman, Gregg Jacobs, Stephanie Anderson, Peter Sakalaukus, U.S. Naval Research Lab. (United States)

Based on observations and modeling studies we have evaluated the impact of submesoscale processes on the development and intensification of offshore narrow (5-10km wide) phytoplankton filaments during late spring-earlier summer and late summer time frames in the Monterey Bay, CA. We have demonstrated that during the late summer time frame, submesoscale processes lead to the development of very productive phytoplankton patches along the edges between the cold jet and warm anticyclonic eddy -- in contrast to the earlier summer time, when the submesoscale processes mix phytoplankton much deeper into the area below the euphotic depth (the depth of light penetration), and productive patches are not maintained. Our results illustrate that during persistent upwelling favorable winds, submesoscale processes can modulate the development and intensification of offshore narrow (5-10km wide) phytoplankton filaments. These processes can incubate the phytoplankton population offshore (as for example, bioluminescent dinoflagellates during August 2003). These offshore phytoplankton filaments can migrate onshore during relaxed winds following the upwelling, and be an additional source of phytoplankton bloom development in and around Monterey Bay. Therefore, the discussed offshore phytoplankton filaments may be a factor in the Bay ecosystem health, as for example, in the development of such events as harmful algae blooms (HABs). All these emphasize the importance of further observational and modeling studies of these submesoscale processes which impact the development and intensification of offshore phytoplankton filaments.

9459-22, Session 5

Factors affecting radiometric calibration of ocean color satellite sensors using AERONET-OC data

Samir Ahmed, Vincius De Paula, Alexander Gilerson, The City College of New York (United States); Menghua Wang, NOAA National Environmental Satellite, Data, and Information Service (United States); Robert A. Arnone, The Univ. of Southern Mississippi (United States)

We recently reported on an approach for radiometric vicarious calibration of ocean color (OC) satellite sensors using radiative transfer (RT) simulations carried out for the full sunlight path of the coupled ocean–atmosphere system based on the aerosol and water-leaving radiance data from two AERONET-OC coastal sites, one located in Long Island Sound (LISCO) and one in the Gulf of Mexico (WaveCIS), for the visible and near-infrared (NIR) bands. The top of atmosphere radiances (TOA) simulated in this manner are then compared with satellite measured TOA radiances to arrive at a quantitative evaluation of the potential for achieving radiometric accuracies of OC satellite sensors. While very high correlations were obtained for all channels with those of the Visible Infrared Imaging Radiometer (VIIRS) for TOA simulated and satellite measured values for both AERONET-OC sites and the vicarious calibration factors derived from this approach were very consistent for both sites in the blue and green spectral regions, much lower than expected gain values were obtained for the red and near infrared (NIR) channels . To better understand these results, and define the potential and limitations of the proposed approach for vicarious calibration, tests are now extended to additional AERONET-OC sites and other open ocean sites with clearer waters and atmospheres and the resulting variability in the red and NIR retrievals and gains is examined, and possible factors limiting AERONET-OC red and NIR retrievals leading to low gain values are assessed.

9459-23, Session 5

Bio-optical model of remote sensing signals in a stratified ocean

James H. Churnside, National Oceanic and Atmospheric Administration (United States)

Several semi-analytic models exist for the inherent optical properties of sea water, at least for Case 1 waters. In these waters, models based on chlorophyll-a concentration seem to be fairly successful. For passive remote sensing, the critical properties are the backscattering coefficient and the zenith diffuse attenuation coefficient. The former describes the total scattering at angles > 0.5ϖ steradians. The diffuse attenuation coefficient is not strictly an inherent optical property, because it depends on the sun angle. The zenith diffuse attenuation coefficient, defined as the attenuation of a diffuse source located at the zenith, depends only on the optical properties of the water. The observed remote sensing reflectance can be estimated from these two parameters and the solar zenith angle. Most of the investigations to date have assumed that the chlorophyll concentration does not vary with depth. This assumption is often quite good, because of the limited penetration of light into sea water. We will consider the case of intense thin plankton layers on a shallow pycnocline, where this assumption might not be valid. For active remote sensing, an additional parameter is important. This parameter is the volume scattering function at a scattering angle of ϖ steradians, which is the sum of contributions from sea water and particles in the water. The sea water contribution is known. The particulate contribution can be modeled as the product of the scattering coefficient, which depends on chlorophyll concentration, and the phase function at ϖ steradians, which does not.

9459-24, Session 5

Ocean and polarization observations from active remote sensing: atmospheric and ocean science applications

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In the past few years, we have demonstrated how the differential attenuation between CloudSat/CALIPSO active instruments allows us to retrieve the optical depth and backscatter phase function (lidar ratio) of aerosols and ice clouds. This methodology lead to the development of a data fusion product currently publicly available at the ICARE archive center (Synergized Optical Depth of Aerosols and Ice Clouds, SODA & ICE).

This low level data fusion of CALIPSO and CloudSat ocean surface echoes has been used to explore different research path. Among them, we can cite:

- In-depth analysis of the lidar ratio of cirrus clouds (Josset et al. 2012)
- Development of a new Millimeter-Wave Propagation Model for the W-Band observations (EMPIRIMA, Josset et al. 2013)
- In-depth analysis of the lidar ratio of sea-spray aerosols (Dawson et al. 2013, Dawson et al. 2014)
- Use of EMPIRIMA and the radar/lidar ocean surface relationship (SODA calibration output) to correct the attenuation of the CALIPSO polarized observation and retrieve the subsurface particulate backscatter coefficients of phytoplankton particles (Behrenfeld et al. 2013)
- Use of SODA for the retrieval of Aerosol multilayer lidar ratio and extinction (R. Ferrare NASA funded research)

We propose to present this research as well as the main features of SODA.

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9459-25, Session 5

Real-time ship monitoring system for offshore maritime surveillance in South Korea

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We have developed the ship monitoring system based on Automatic Identification System (AIS) and FMCW radar, and a prototype system

including Synthetic Aperture Radar (SAR) was introduced in the conference (IGARSS 2013; SPIE DSS 2013) and the Journal of Navigation (2012). Offshore is a restricted area to get in-situ data such as AIS, video and radar when satellite-based surveillance system is applied to the region. In this work we consider the ocean towers as a hub in the adjacent sea of Korean Peninsula and transmit the field information collected at the station via the geostationary satellite, COMS(Communication, Ocean and Meteorology Satellite). At the land station, it is possible to integrate the all availale data and monitor ship traffic in near real time. We applied the integrated ship surveillance system to the Gageocho Ocean Science Station in the Yellow Sea of South Korea using SAR, FMCW-radar and AIS. AIS and radar provide a real-time ship monitoring capability, and when SAR image is available it is converted to the satellite mode which operates by standards of the time and position of satellite data. In addition to that, we will introduce an algorithm for integrating ship information.

9459-26, Session 6

Ocean thermal fronts detection in the full thermal IR imagery

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Ocean thermal fronts are indicators of intense ocean dynamics. Being highly variable in space and time, they difficult to predict from prior or ancillary data, and should be identified from the satellite data itself. Customarily, front detection from satellite observations is done on cloud- and ice-free sea surface temperature (SST) imagery. However, cloud and ice masks may not be fully accurate, and mistakenly label some cloud and ice as clear sky, and vice versa. As a result, the identified thermal fronts may also include boundaries between clear sky and thin cloud, and quasi-linear textures of (e.g. cirrus) cloud/cloud transitions. More importantly, false alarms (i.e. when ocean features have been screened out as clouds) often occur, preventing identification of thermal fronts under masked area. Sea ice mask also leads to inclusion of ice features in the dynamic areas where sea ice cover might be rapidly changing. Regions with new ice formation often resemble the typical apparent whirl-like ocean pattern, affecting thermal front detection if not masked out. We explore an approach that does not require a pre-computed clear sky or sea ice mask, but rather performs the search on the whole water domain and relies on the gradient behavior of the derived SST field, connectivity of the front, the local SST statistics on both sides of the front, as well as bimodality of the SST distribution in the vicinity of the thermal front. The algorithm has been tested on VIIRS Level 2 full swath that includes bow tie regions.

9459-27, Session 6

A fast, robust, adaptive destriping algorithm for SNPP VIIRS and Terra/Aqua MODIS SST

Karlis Mikelsons, GST, Inc. (United States) and NOAA National Environmental Satellite, Data, and Information Service (United States); Alexander Ignatov, NOAA National Environmental Satellite, Data, and Information Service (United States); Marouan Bouali, Univ. de São Paulo (Brazil); Yury Kihai, GST, Inc. (United States) and NOAA National Environmental Satellite, Data, and Information Service (United States)

Radiometric performance of MODIS and VIIRS sensors has dramatically improved over the AVHRR, and much more stringent calibration efforts and practices are in place. Nevertheless, the multi-detector MODIS and VIIRS instruments are subject to striping artifacts. A robust adaptive destriping algorithm recently introduced by Bouali and Ignatov [1] was optimized and now operationally applied at NOAA to remove striping artifacts from the S-NPP VIIRS brightness temperature (BT) data. The algorithm is also run with MODIS data onboard Terra/Aqua, in an experimental mode. We demonstrate improved image quality of VIIRS and MODIS BTs in bands centered at 3.7, 11 and 12 μm, and significant improvements in the SST imagery derived from the destriped BTs. The algorithm proves capable of removing the striping noise, while preserving the fine natural contrasts of the original satellite imagery. The same algorithm is also applied to remove striping artifacts from the VIIRS and MODIS “optional SST” bands centered at 4 and 8.5 μm. Destriping is critically important for several SST applications relying on accurate BT or SST gradient data, including pattern recognition improvements to cloud mask and ocean front detection. We also present the results of statistical characterization of striping artifacts in the VIIRS and MODIS thermal IR bands under various conditions. Our implementation of destriping is computationally very efficient, adding only a fraction of time to the SST data processing flow. It is currently used in the NOAA VIIRS operations as well as reprocessing efforts.

[1] M. Bouali and A. Ignatov, “Adaptive reduction of striping for improved sea surface temperature imagery from Suomi National Polar-orbiting Partnership (S-NPP) Visible Infrared Imaging Radiometer Suite (VIIRS),” JTech, 31, 150–163 (2014).

9459-28, Session 6

Evaluation of VIIRS SST fields through the analysis of overlap regions between consecutive orbits

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Sea Surface Temperature (SST) retrievals derived from data acquired by the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on-board the S-NPP satellite can be produced to the edge of the scan with approximately constant spatial resolution and little degradation in quality. Full swath processing creates significant areas of overlap between consecutive orbits. These overlap regions are found at all latitudes and grow larger away from the equator. In this study, we use the overlap regions to evaluate VIIRS SST. For simplicity, as a first step, we concentrate on low and mid-latitudes to avoid multiple orbits overlap and difficulties with nighttime and daytime definitions. The motivation for this study comes from the observation that SST fields stay relatively unchanged within the approximately 100 minutes which separate two consecutive orbits, even in dynamic regions. As such, inconsistencies between SST values from consecutive orbits are likely indications of degraded quality. This presentation looks at two potential sources of inconsistencies between orbits. One potential source of inconsistencies results from the unequal response of the SST equations when observing a scene from differing view angles. To take into account the effect of varying atmospheric conditions in the response, different ocean regions are examined. Another source of inconsistencies addressed in this study is caused by undetected data contamination, for example, clouds which can produce quickly changing localized patterns. In this case, overlap analysis is particularly effective because the wide coverage of the overlap regions can spotlight areas for which buoy coverage is sparse and problems overlooked. This study will present results for two VIIRS SST products: The one from the Naval Oceanographic Office (NAVOCEANO) which is assimilated in the Navy Ocean Models, and the Advanced Clear-Sky Processor for Oceans (ACSPO) product from the National Oceanic and Atmospheric Administration (NOAA) center for Satellite Applications and Research (STAR). Global statistics based on drifting buoys for both NAVOCEANO and NOAA products complete the analysis.

9459-29, Session 6

Seasonal trends of ocean SST products characterized by the differences in orbital overlaps for waters types

Robert A. Arnone, Ryan A. Vandermeulen, The Univ. of Southern Mississippi (United States); Jean-François P. Cayula, Vencore, Inc. (United States); Alexander Ignatov, NOAA National Environmental Satellite, Data, and Information Service (United States)

The uncertainty of the SST products from the VIIRS satellite is examined using consecutive orbital overlaps. The overlapping region on the left and right side of swath at 23-35 degree latitude is approximately 500 pixels which occur within 100 minutes. This can provide a total of 4 SST products (2 day and 2 night) per day. By assuming the ocean products should be similar on each side of the swath in this short time period, we can evaluate the uncertainty of products and how rapidly the SST is changing. VIIRS ACSPO product from NOAA STAR was used to determine the difference in SST at the overlaps. These product changes were evaluated between consecutive orbits to characterize how the products are impacted on each side of the swath by solar and sensor angles, and sensor characterization. Sensitivity of the products to water types was evaluated by analyzing product differences for open ocean, shelf and coastal waters. Besides the absolute diurnal SST changes that can occur within 100 minute time, the product differences can result across the swath from surface glint, sensor angular impacts and sensor characteristics such as half angle mirror side (HAM) and calibration. The seasonal trends of the difference in SST at the overlaps for these water masses were tracked on a monthly basis. The unique capability of using the same VIIRS sensor for self-characterization can provide a method to define the uncertainty of ocean products and characterize the diurnal changes for different water types.

9459-30, Session 6

Suppressing the noise in SST retrieved from satellite infrared measurements by smoothing the differential terms in regression equations

Boris Petrenko, NOAA National Environmental Satellite, Data, and Information Service (United States) and GST, Inc. (United States); Alexander Ignatov, NOAA National Environmental Satellite, Data, and Information Service (United States); Yury Kihai, NOAA National Environmental Satellite, Data, and Information Service (United States) and GST, Inc. (United States)

SST retrieval systems widely use regression algorithms based on Nonlinear (NLSST) and Multichannel (MCSST) approaches. In order to improve the atmospheric correction, the NLSST and MCSST equations include the terms dependent on the difference between the brightness temperatures in the spectral bands with different atmospheric absorption. A side effect of using these terms is amplification of the radiometric noise present in individual BTs. The random noise is often clearly seen on images of retrieved SST and may affect the performance of high-level image processing algorithms for detecting thermal fronts and small-scale SST anomalies. Noise of radiometric origin can also affect the precision of retrieved SST, determined as a global standard deviation between retrieved and in situ SSTs. Some processing systems (e.g., EUMETSAT OSI-SAF) incorporate noise suppression algorithms based on spatial smoothing of the differential terms in the SST equations. Recently, an algorithm of this type has been also implemented and tested within the NOAA Advanced Clear-Sky Processor for Oceans (ACSPO) system. The ACSPO smoothing algorithm aims at suppressing the random noise in SST while preserving natural SST variations and the initial spatial resolution, and minimizing the processing time. This presentation describes the ACSPO noise suppression algorithm and discusses results of its initial evaluation based on SST imagery and matchups of NOAA/Metop AVHRRs (GAC and FRAC), Terra/Aqua MODIS and SNPP/JPSS VIIRS with in situ data.

9459-31, Session 7

VIIRS SST products and monitoring at NOAA

Alexander Ignatov, John Stroup, Yury Kihai, Boris Petrenko, Irina Gladkova, Prasanjit Dash, Xingming Liang, Feng Xu, Xinjia Zhou, Karlis Mikelsons, John Sapper, NOAA National Environmental Satellite, Data, and Information Service (United States)

NOAA produces Level 2 and 3 SST products from VIIRS onboard S-NPP/JPSS platforms. Over the past year, the Interface Data Processing Segment (IDPS) system was discontinued, and the NOAA heritage Advanced Clear-Sky Processor for Oceans (ACSPO) system designated as operational JPSS product. Destriping was operationally implemented. VIIRS SST is 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 and future plans are discussed.

9459-32, Session 7

Monitoring and validation of AVHRR FRAC, MODIS, (A)ATSR and VIIRS high-resolution sea surface temperatures

Prasanjit Dash, Alexander Ignatov, Yury Kihai, John Stroup, Boris Petrenko, John Sapper, NOAA National Environmental Satellite, Data, and Information Service (United States)

Monitoring and validation of global sea surface temperature (SST) products are routinely performed by the NOAA SST Quality Monitor (SQUAM) and the diagnostics are provided online. Initially, only NOAA SST products were monitored, but since SQUAM inception in 2008 all major global polar infrared SST products either have been added, or are being added to the system.

SQUAM is organized following the product levels (levels 2, 3 4; L2, L3, L4), as outlined by the Group for High resolution SST (GHRSST) specifications.

A number of global L2 high-resolution (1km or better) SST products are generated from various satellites and sensors, by different countries and agencies using a wide range of sampling, cloud screening and SST retrieval algorithms. The SQUAM high-resolution (HR) module (www.star.nesdis.noaa.gov/sod/sst/squam/HR/) provides diagnostics of these HR L2 SSTs. Currently, several HR products are ingested and analyzed including the NOAA Advanced Clear-Sky Processor for Oceans (ACSPO), NOAA Interface Data Processing Systems (IDPS), Eumetsat Ocean & Sea Ice Satellite Application Facility (O&SI SAF), US NAVOCEANO and ESA (A) ATSR Reprocessing for Climate (ARC). The ACSPO products are from NPP VIIRS, Metop-A/B AVHRR FRAC and Terra/Aqua MODIS. The other products include IDPS (NPP VIIRS), O&SI SAF (Metop-A AVHRR), NAVO (NPP VIIRS) and the ARC (A/ATSR series).

All HR L2 products are consistently validated against quality controlled in situ data (from another NOAA system, in situ SST Quality Monitor, iQuam, www.star.nesdis.noaa.gov/sod/sst/iquam/), monitored against several level-4 gap-free SSTs (CMC, OSTIA, and Reynolds), and cross-compared, employing the established SQUAM metrics. Results of monitoring and validation from SQUAM-HR, and additionaly, and random error characterization employing a triple-collocation method will be presented.

9459-33, Session 7

Assimilation of ECMWF versus GFS profiles in fast CRTM for SST retrievals at NOAA

Xingming Liang, NOAA National Environmental Satellite, Data, and Information Service (United States) and Colorado State Univ. (United States) and Cooperative Institute for Research in the Atmosphere (United States); Alexander Ignatov, NOAA National Environmental Satellite, Data, and Information Service (United States)

NOAA SST system, Advanced Clear-Sky Processor for Ocean, simulates top-of-atmosphere clear-sky brightness temperatures in bands at 3.7 (IR37), 11 (IR11), and 12μm (IR12). Community Radiative Transfer Model (CRTM) is used in conjunction with first guess SST and atmospheric profiles. Based on earlier sensitivity analysis to first-guess SST (Saha et al., 2012), initial SST implementation (Reynolds) was replaced by the Canadian Met Centre (CMC) product. This study additionally checks sensitivity to atmospheric profiles, by comparing the current implementation of NCEP Global Forecast System (GFS, 1° lat-lon resolution, 26 levels) with the European Center for Medium range Weather Forecasting (ECMWF, 0.25°, 97 levels). The comparisons are performed in the Monitoring of IR Clear-sky Radiances over Oceans for SST (MICROS; www.star.nesdis.noaa.gov/sod/sst/micros/) system, which analyzes Model minus Observation (M-O) biases for several AVHRR, MODIS and VIIRS sensors. Preliminary results based on four-month global data show that the number of clear sky pixels slightly increases. In IR37, the global mean M-O biases (currently, ~0.2-0.3K) and standard deviations (currently, STD<0.5K), are only minimally affected. In IR11 & IR12, the mean biases and STDs (currently, both ~0.6K) are reduced, and become closer to IR37. This suggests that the ECMWF has more moisture, and this mainly affects M-O biases in the longwave bands. The effect is generally positive - the large warm spots in M-O biases in the tropics are reduced, and even reverted to negative M-O biases, suggesting that ECMWF overestimates water vapor. We plan to also include ERA-Interim and MERRA profiles in the comparisons.

9459-34, Session 7

A new deterministic inversion technique for sea surface temperature retrieval from MODIS radiances

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The MODIS imager contains 16 channels in the thermal infrared, making it an attractive instrument to study the atmospheric and oceanic sciences. Even for satellite-derived sea surface temperature (SST) retrievals, the dynamics of atmospheric conditions need to be characterized by the satellite measurements to retrieved good quality SST. The current MODIS SST product available from the Group for High Resolution SST (GHRSST) Global Data Assembly Center (GDAC), uses a regression-based inversion method and only two and/or three channels. The few coefficients of the regression based retrieval method are unable to adequately capture the wide atmospheric variability and, as a result, a significant error is embedded in retrieved SST. We will demonstrate in this talk that the MODIS SST can be retrieved two times higher accuracy compared to the current GHRSST SST, by using using more channels and a physical deterministic-based modified total least squares (MTLS) method. This study also includes the SST4, NLSST, optimal estimation based SST retrieval for comparison purposes. The information content and noise analysis of these retrievals, and the retrieval error due to the quality of cloud detection will be discussed.

9459-35, Session 7

Long-term analysis of AVHRR calibration in thermal IR channels

Kai He, GST, Inc. (United States) and NOAA National Environmental Satellite, Data, and Information Service (United States); Alexander Ignatov, NOAA National Environmental Satellite, Data, and Information Service (United States); Yury Kihai, GST, Inc. (United States) and NOAA National Environmental Satellite, Data, and Information Service (United States); Xingming Liang, NOAA National Environmental Satellite, Data, and Information Service (United States) and Colorado State Univ. (United States); Changyong Cao, NOAA National Environmental Satellite, Data, and Information Service (United States); John Stroup, NOAA National Environmental Satellite, Data, and Information Service (United States) and Stinger Ghaffarian Technologies (United States)

AVHRR clear-sky brightness temperatures (BTs) and sea surface temperatures (SSTs) are produced at NOAA by the Advanced Clear-Sky Processor for Oceans (ACSPO). Monitoring of IR Clear-sky Radiances over Oceans for SST (MICROS; www.star.nesdis.noaa.gov/sod/sst/micros/) suggests that artifacts in SSTs and BTs are strongly correlated. This study analyzes long-term trends of AVHRR Level-1b data (calibration slope, intercept, black body temperature, etc.) for NOAA polar-orbiting satellites (NOAA-15 to -19) and the MetOp series (MetOp-A and –B) and their links with BTs.

Long term time series of AVHRRs calibration coefficients for some platforms (e.g., MetOp-A) are highly consistent and show a smooth monotonic trend over time due to sensor degradation. For some other platforms (e.g. NOAA-16), the variations are strong and non-monotonic in time, and are apparently correlated with the temperature of the sensor. In short term, calibration is more stable over the part of an orbit when the satellite is in the Earth shadow (referred to as “satellite night”), and more variable when the satellite is in direct Sun light (“satellite day”). Significant day-night differences are most pronounced in the shortwave band 3B, suggesting that the “daytime artifacts” are due to e.g. sun impingement of AVHRR black body.

For thermally stable sensors, improvements to AVHRR calibration are explored based on the use of “the best part of an orbit” (“satellite night”) or best parts of satellite lifetime, rather than the current line-by-line approach. For thermally unstable sensors or periods, a different calibration algorithm is needed. Work is underway to explore these improvements.

9459-36, Session 7

Identification of sea surface temperature (SST) variability areas through a statistical approach using remote sensing and numerical ocean model data

Jesus Loeches, STO-CMRE (Italy); Raul Vicen, North Atlantic Treaty Organization (Italy) and STO-CMRE (Italy); Giuliana Pennucci, Aniello Russo, STO-CMRE (Italy)

An understanding of environmental variability (stability/instability) is important to support operational planning of expeditionary warfare and littoral operations, as well as for preparing the Recognized Environmental Picture (REP). Specifically, the identification of environmentally stable/unstable areas helps the planning of maritime operations, increasing their likelihood of success. The purpose of the paper is to describe a methodology to form and interpret an initial spatial-temporal variability characterization of maritime areas from Remote Sensing (RS) and Numerical Ocean Model (NOM) data. As a case study, the analysis of the sea surface temperature (SST) in the Black Sea from historical time-series of RS imagery and NOM data is considered. The results of the analysis are validated with in situ measurements from moorings. Identification of gaps of geospatial information is also done in this study. The analysis is focused on monthly spatial-temporal variability of the SST, generating stability maps displaying the geospatial distribution of environmentally stable/unstable areas along a year. The results show how the proposed methodology captures the temporal variability of the SST in the Black Sea, being compared with in situ measurements, and provides useful information for the identification of environmentally stable/unstable areas. The results show a general agreement in the variability with both RS and NOM data, when RS imagery may be used for the present analysis, i.e. when low cloud coverage is given. This paper demonstrates that when RS imagery gaps are not negligible (e.g. due to high cloud occurrence in winter season), these gaps could be filled with NOM data.

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9460-1, Session 1

Reconnaissance architecture in near space

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Today, reconnaissance architecture is established to carry out the reconnaissance needs of the states. This architecture includes air platforms like reconnaissance aircrafts with camera systems, unmanned air vehicles and satellites which provide valuable air pictures. When we take care of the irregular warfare, once again it could be easily proved that the reconnaissance systems are crucial for the states in order to obtain real time and correct data.

With the unprecedented advances in technology, manned reconnaissance systems become unmanned because of their low risk. Although satellites and unmanned aircraft systems are succesful as reconnaissance, in order to get more mission-effective and cost-effective data, scienciests are begin to study on unmanned air platforms which are flying in the newly discovered area called near space.

In this essay, we will see the term of near space, its characteristics, using areas, its importance for the reconnaissance and the latest developments. Besides we will study on the pros and cons with the comparison of satellites and unmanned air vehicles.

9460-2, Session 1

Hybrid consensus UAV formation control

Haci Mehmet Guzey, Missouri Univ. of Science and Technology (United States); Travis A. Dierks, DRS Sustainment Systems, Inc. (United States); Jagannathan Sarangapani, Missouri Univ. of Science and Technology (United States)

In this paper, hybrid consensus based formation control for a team of Unmanned Aerial Vehicles (UAV's) is considered. A hybrid consensus based formation controller is applied for UAV's moving at fixed altitudes to drive them to a goal point while maintaining a specified formation. The proposed hybrid automaton consists of two discrete states, each with continuous dynamics: a regulation state and a formation keeping state. The controller in the regulation state uses local state information to achieve its objective while the formation controller utilizes the state and controller information of neighboring UAV's. Consequently, the UAV's switch between the control objectives of formation keeping and goal seeking in route to their goal points. The switching behavior creates hybrid dynamics from the interactions between the continuous and discrete states making the stability analysis of the system more complex than considering purely discrete or purely continuous. Therefore, the stability of the hybrid approach is proven by using multiple Lyapunov functions and also considers the switching conditions between the regulation and the formation states. The Lyapunov based approach demonstrates that the formation errors converge to a small bounded region around the origin and the size of the bound can be adjusted by using the switching conditions. Convergence to goal position while in formation is also demonstrated in the same Lyapunov analysis, and simulation results verify the theoretical conjectures.

9460-3, Session 1

Design of a disguised miniature unmanned aerial vehicle (UAV) system with surveillance function

Terence K. L. Goh, Donny Ng, Ian V. H. Tam, SIM Univ. (Singapore)

Fixed wing and rotary wing unmanned aerial vehicles (UAVs) have been extensively used and researched in commercial and military applications. Disguising the unmanned aerial vehicle (UAV) as a bird with a flapping wing platform is a relatively new concept but it holds potentially exciting reconnaissance and surveillance UAV applications. There are no established methodologies in designing and developing a flapping wing system in the industry yet.

This paper presents on efforts to explore and develop methodologies to build successful flapping wing prototypes and incorporate systematic and effective functional test approach for various essential system components and payloads. Analysis and design tool for unsteady flapping wing aerodynamics as well as structural design and its limitations have been investigated and to be presented.

9460-4, Session 2

IR CMOS: an ISR solution for Nightvision and See Spot

Martin U. Pralle, James E. Carey, Chris J. Vineis, SiOnyx Inc. (United States)

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: daytime imaging out to 2Km

9460-5, Session 2

Results from an experiment that collected visible-light polarization data using unresolved imagery for classification of geosynchronous satellites

Andy Speicher, Mohammad A. Matin, Univ. of Denver (United States); Francis K. Chun, Roger D. Tippets, U.S. Air Force Academy (United States); David Strong, United States Air Force Academy (United States)

In order to protect critical military and commercial space assets, the United States Space Surveillance Network must have the ability to positively identify and characterize all space objects. Unfortunately, positive identification and characterization of space objects is a manual and labor

intensive process today since even large telescopes cannot provide resolved images of most space objects.

The objective of this study was to collect and analyze visible-spectrum polarization data from unresolved images of geosynchronous satellites taken over various solar phase angles. Different collection geometries were used to evaluate the polarization contribution of solar arrays, thermal control materials, antennas, and the satellite bus as the solar phase angle changed. Since materials on space objects age due to the space environment, their polarization signature may change enough to allow discrimination of identical satellites launched at different times. Preliminary data suggests this optical signature may lead to positive identification or classification of each satellite by an automated process on a shorter timeline.

The instrumentation used in this experiment is a new ground-based asset for the United States Air Force Academy (USAFA) Department of Physics. The system consists of a 20-inch Ritchey-Chretien telescope and a dual focal plane optical train fed with a polarizing beam splitter. Following a rigorous calibration, polarization data was collected on six geosynchronous satellites built by different manufacturers and launched several years apart. When Stokes parameters were plotted against solar phase angle, the data indicates that a polarization signature from unresolved images may have promise in classifying specific satellites.

9460-6, Session 2

Laser links for mobile airborne nodes

Wolfgang Griethe, G2Aerospace GmbH (Germany); Markus Knapek, Joachin Horwath, ViaLight Communications GmbH (Germany)

The communication link between the Ground Control Station (GCS) and Remotely Piloted Aircraft (RPA) is a key component of the overall system. Without such a reliable link the Unmanned Vehicle is not operable.

Today's common practice is that the radio link, typically operated in ku-band, is used for both, control of the aircraft as well as transmission of intelligence data. The result is a big problem: While the aircraft could be securely controlled with relatively low bandwidth, enormous bandwidths for the transmission of intelligence data is required which is often not available. Of course, the today's fixed and limited frequency allocation of the available spectrum creates a hard limit on the amount of usable capacity. In addition, the current use of the radio ku-band for UAS mobile communications neither complies with ITU, nor is it regulated by national authorities. Incidentally, this will cause another future problem in terms of the airworthiness certification of Remotely Piloted Aircrafts.

Finally, the use of sensors with permanent increased resolution, the parallel operation of different sensor types aboard the aircrafts and also the rapidly increasing numbers of RPAs aggravate the bandwidth problem. Anyway, bandwidth is a limited resource that needs to be managed. The current methods for solving the problem are manyfold and range from compression technologies and high-order modulation techniques until to frequency reuse.

Anyway, all these methods may be useful and in some cases also effective, but they do not solve the fundamental problem of scarce bandwidth, but remind rather of the problem of squaring the circle.

According to the authors, the problem is only solvable if the vital control link of the RPA, is separatly operated from the data link. Suggested is the future control of RPA's with narrowband fault-resistant radio links, while reconnaissance data of Medium Altitude Long Endurance (MALE) and High Altitude Long Endurance (HALE) vehicles should be transferred into frequency spectra that are not subject of coordination by ITU, i.e. optical frequencies. Consequently the paper discusses a mobile airborne node which uses laser communications to meet future data capacity requirements of RPAs.

In this way reconnaissance data can be transmitted over several hundred miles from RPA to RPA. The tactical advantages of the airborne node are highlighted. It is shown that laser communications can be operated in the upper layers of the atmosphere with high reliability. Special problems and technical challenges of laser communications aboard RPAs are addressed. The design of a laser terminal with lighter steerable optics is described in detail. Finally, the advantages of a mobile airborne node compared to a space network are underlined.

9460-7, Session 2

Small SWAP 3D Imaging Flash Ladar for Small Tactical Unmanned Air Systems

Alan W. Bird, Scott A. Anderson, Michael D. Wojcik, Scott E. Budge, Utah State Univ. (United States)

The Space Dynamics Laboratory (SDL), working with Naval Research Laboratory (NRL) and industry leaders Advanced Scientific Concepts (ASC) and Hood Technologies, has developed a small SWAP (size, weight, and power) 3D Flash LADAR (LAser Detection And Ranging) sensor system concept design for small tactical unmanned air system (STUAS). The design utilizes an ASC 3D Flash LADAR camera and laser in a Hood Technologies gyro-stabilized gimbal system. The design is an autonomous, intelligent, geo-aware sensor system that supplies real-time 3D terrain and target images. Flash LADAR and visible camera data are processed at the sensor using a custom digitizer/frame grabber with compression. Mounted in the aft housing are power, controls, processing computers, and GPS/INS. The onboard processor controls pointing and handles image data, detection algorithms and queuing. The small SWAP 3D Flash LADAR sensor system generates georeferenced terrain and target images with a low probability of false return and <10 cm range accuracy through foliage in real-time. The 3D Flash LADAR is designed for a STUAS with a complete system SWAP estimate of <9 kg, <0.2 m3 and <350 W power. The system is modeled using LadarSIM, a MATLAB® and Simulink®-based LADAR system simulator designed and developed by the Center for Advanced Imaging LADAR (CAIL) at Utah State University. We will present the concept design and modeled performance predictions.

9460-8, Session 2

EM modeling of far-field radiation patterns for antennas on the GMA-TT UAV

Anne I Mackenzie, NASA Langley Research Center (United States)

The NASA AIRSTAR Program, conducted by the NASA Langley Research Center, flies various research unmanned aerial vehicles (UAV's) in order to simulate how the corresponding full-scale manned aircraft will behave in flight upset conditions. The GMA-TT UAV is a 16-foot scale model of a larger, generic T-tail aircraft, and represents a class of regional jet transports. Before flying the GMA-TT, it is necessary to situate numerous antennas on the UAV to enable systems such as flight termination (UHF-band), automatic dependent surveillance - broadcast (ADS-B, UHF-band), command and control (L and S-bands), data relay (L and S-bands), and global positioning system (GPS, L-band). Each antenna must be placed so that it can communicate with another antenna, which may be on the ground in a mobile operating station (MOS) or overhead on a satellite. Communications must be maintained with the GMA-TT whether it is on the runway or in the air and regardless of attitude.

To optimize communication with the UAV, electromagnetic (EM) simulations can be performed to predict the performance of each antenna on the aircraft. Simulated far-field radiation patterns tell the amount of power radiated by the antennas and the aircraft together, taking into account blockage by the aircraft as well as radiation by conducting and dielectric portions of the aircraft. With a knowledge of the polarization and distance of the two communicating antennas, e.g. one on the UAV and one on the ground, and the transmitted signal strength, a calculation may be performed to find the strength of the signal travelling from one antenna to the other and to check that the transmitted signal meets the receiver system requirements for the designated range. In order to do this, the antenna frequency and polarization must be known for each antenna, in addition to its design and location. The permittivity, permeability, and geometry of the

UAV components must also be known. The full-wave method of moments (MOM) solution produces the appropriate dBi radiation pattern in which the received signal strength is calculated relative to that of an isotropic radiator.

Measurements of the GMA-TT outer covering material revealed the carbon fiber-reinforced epoxy composite to be highly reflective. Two types of antennas, blade antennas and conformal antennas, were modeled on the surface of the GMA-TT. Radiation patterns were calculated for various antennas at a number of possible locations, including the winglets, wings, fuselage, and tail. Some conclusions were drawn regarding the characteristics of antenna patterns produced by the different antenna designs and locations.

Modeling was performed on an HP Z820 Workstation computer, making use of the multilevel fast multipole (MLFMM) method in FEKO software.

9460-23, Session 2

Low-SWaP 4-axis stabilized Gimbal system and enabled missions

Karl J. Pendergast, Adsys Controls, Inc (United States)

The utility of small UAS (SUAS) has exploded in the past decade with increasingly complex mission requirements being levied on SUAS platforms. Inevitably, this means smaller and more capable payloads with focus on long range ISR, laser designation/targeting, geolocation, high definition imagery, video compression, advanced image processing, and increased payload autonomy. Key limitations for low-SWaP payloads have been in precision pointing/stabilization, sensor modularity, and video processing/compression. Adsys Controls, Inc. will present an overview of our new 6" class Arrow gimbaled sensor system, and discuss its design solution for this challenging next generation mission set. We will discuss the Arrow architecture with 4-axis stabilization mechanism and advanced on-board video processing system. We will also present simulation-based stability analysis and flight data.

9460-10, Session 3

Fusion of video and radar comparison to 3D ladar for activity recognition

David Tahmoush, U.S. Army Research Lab. (United States)

No Abstract Available

9460-11, Session 3

Real-time embedded technology for enhancing long-range imagery

Aaron L. Paolini, Daniel L. Hertenstein, Eric J. Kelmelis, James Bonnett, Paul A. Fox, EM Photonics, Inc. (United States)

Many ISR applications require constant monitoring of targets from long distance. When capturing over long distances, imagery is often degraded by atmospheric turbulence. This adds a time-variant blurring effect to captured data, and can result in a significant loss of information. To recover it, image processing techniques have been developed to enhance sequences of short exposure images or videos in order to remove frame-specific scintillation and warping. While some of these techniques have been shown to be quite effective, the associated computational complexity and required processing power limits the application of these techniques to post-event analysis.
To meet the needs of real-time ISR applications, video enhancement must be done in real-time in order to provide actionable intelligence as the scene unfolds. In this paper, we will provide an overview of an algorithm capable of providing the enhancement desired and focus on its real-time implementation. We will discuss the role that both FPGAs and GPUs play in enabling real-time performance and the trade-offs of using each platform. This technology can be used to add performance to ISR applications by improving the quality of long-range imagery as it is collected and effectively extending sensor range.

9460-12, Session 3

Characterization of UAV hover patterns in support of superresolution research

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

Prior work has demonstrated the efficacy of a hierarchical super-resolution technique, based on Schultz, Meng and Stevenson's Bayesian multiframe resolution enhancement approach, for enhancing image data similar to that collected by UAVs. This technology relies on sub-pixel movement between images (which was artificially created during the prior work), ideally producing five images: one center image and four surrounding images with a one-half pixel diagonal offset (in each diagonal direction).

This paper characterizes a Parot AR.Drone's hover movement (the small movements made by the craft for position keeping to correct for air movement and mechanical or electrical irregularities) as an initial step towards evaluating the efficacy of UAV hover patterns for creating imagery suitable for this super-resolution technique. It characterizes the UAV's hover pattern to answer two questions. First it seeks to determine whether hover movement may produce the requisite level of movement for super-resolution use. Second, it characterizes the distances from the target at which this hover pattern movement provides a suitable level of shifting. Multiple distances and resolution levels are considered.

Based on this data, the efficacy of the use of the hover movement is evaluated. Then, the impact of being able to utilize this hover movement to aid super-resolution is discussed. It is compared and contrasted to the utility of utilizing directional movement, qualitatively, to this same end and benefits and drawbacks of the two approaches are discussed. Finally, the potential utility of super-resolution onboard UAVs, and how this could be enabled by the hover-pattern collection technique is discussed and future work is considered.

9460-13, Session 4

Aerial video mosaicking using binary feature tracking

Breton L. Minnehan, Andreas E. Savakis, Rochester Institute of Technology (United States)

As the cost of Unmanned Aerial Vehicles (UAVs) decreases, UAVs become an increasingly attractive platform for applications ranging from reconnaissance to disaster relief and infrastructure monitoring. Creating detailed aerial maps from UAV data requires fast and accurate video mosaicking methods. Traditional mosaicking techniques rely on inter-frame homography estimations that are cascaded through the video sequence. Keypoint matching algorithms, such as kd-trees, are typically used to determine the correspondence of SIFT or SURF keypoints between frames, but small errors may accumulate over successive frames to larger discrepancies. Large moving objects pose additional challenges to the traditional mosaicking methods. This paper presents a video mosaicking method that uses a keypoint tracking approach for matching keypoints between frames to improve both efficiency and robustness. Tracking is based on dictionaries of local binary descriptors and leverages the spatial locality of the keypoints to simplify the matching process. Our method is robust to cascaded errors by determining the homography between each frame and the ground plane rather than the prior frame. The frame-to-ground homography is calculated based on the relationship of each point's image coordinates and its estimated location on the ground plane. Robustness to moving objects is integrated into the homography estimation step through detecting anomalies in keypoints motion and eliminating their

influence. The resulting mosaics are of high accuracy and can be computed in real time.

9460-14, Session 4

Background image understanding and adaptive imaging for vehicle tracking

Anthony Vodacek, Matthew J. Hoffman, Burak Uzkent, Bin Chen, Rochester Institute of Technology (United States)

Surveillance of vehicles from a remote platform using an imaging sensor is often done with a pointing sensor and small field of view, limiting the tracking to a single vehicle. Other sensors have been designed to observe a wider area, but automated tracking algorithms for these sensors often track any vehicle moving in the scene, even ones that may be irrelevant to the task. Automated tracking algorithms may also fail when vehicles become obscured or otherwise enter scenarios that make imaging difficult. We describe our effort to create a imaging-based vehicle tracking system that uses the principles of dynamic data driven applications systems to observe, model, and collect new within a dynamic feedback loop. Several unique aspects of the system include tracking of user-defined vehicles, the use of an adaptive sensor that can change modality, and a reliance on background image understanding to improve tracking and minimize error. We describe the system and show results demonstrated within the DIRSIG image simulation model that show improved tracking results for the system.

9460-15, Session 4

Enhanced performance for the interacting multiple model estimator with integrated multiple filters

Madeleine G. Sabordo, Elias Aboutanios, The Univ. of New South Wales (Australia)

In this paper, we propose a new approach to target visibility for the Interacting Multiple Model (IMM) algorithm. The concept of target visibility is used as a basis for deciding the status of a track. We say that a target is visible if it exists and is detectable by the sensor. The probability of visibility is recursively calculated based on the following assumptions:

1) Target visibility sequence {v} with outcomes 1 and 0 can be modeled as a first-order homogeneous Markov chain with transition probabilities ψ01 (probability that the target switches from invisible at time k?1 to visible at time k) and ψ11 (probability that the target remains visible).

2) Clutter returns received at different sampling times are independent and target detection is independent of clutter detections.

3) The number of validated measurements, denoted by m(k,t), of visible target at each time step is a binary random variable which takes on the value 1 or 0. The non-zero conditional probability is P{m(k,t) = 1|θ(k),Z(kθ1)}, where θ(k) is the event that the target is visible at time k and Z(k–1) is the set of measurements up to the previous time step.

In addition to this concept, we employ an integrated multiple filter (IMF) which engages two filters to deal with data association. Unlike conventional practice in associating measurements to tracks where each technique is used in isolation throughout the recursive process, in this work we employ both the Nearest Neighborhood (NN) filter and the Probabilistic Data Association (PDA) filter to alternately associate measurements to track depending on the density of measurements that fall inside the validation region. We investigate five model sets that model the dynamic motion of a manoeuvring target. The model sets are incorporated into the IMM-IMF tracker to estimate the behaviour of the target. We employ the Dynamic Error Spectrum (DES) to assess the effectiveness of the tracker with target visibility concept incorporated and to compare the performance of the model sets in enhancing tracking performance. Results show that the new version of target visibility significantly improves the performance of the tracker. Simulation results also demonstrate that the 2-Constant Velocities-Constant Acceleration-2 Coordinated Turn (2CV-CA-2CT) model set proves to be the most robust at the cost of computational resource. The Constant Velocity and Constant Acceleration (CV-CA) model set is the fastest. However, it is the least robust in terms of performance. These results assist decision makers and researchers in choosing appropriate models for IMM trackers. Augmenting the capability of the tracker improves the ability of the platform to identify possible threats and consequently, enhance situational awareness.

9460-16, Session 5

Improving change detection results with knowledge of registration uncertainty

Andrew J. Lingg, Etegent Technologies, Ltd. (United States); Brian D. Rigling, Wright State Univ. (United States)

Uncertainty in the registration between two images remains a problematic source of error in performing change detection between them. We present a method for reducing the impact of misregistration based upon a statistical characterization of the uncertainty in the estimate of the registration transformation. When using a feature-point based registration algorithm, we can compute a Cramer-Rao lower bound (CRLB) on the estimate of the registration transformation based on an assumed covariance in the feature-point locations. This information is used to estimate the variance on the location at which pixels will appear in the registered image, which is used to estimate the bias and variance introduced into the pixel intensities by registration uncertainty. Here, we use this information to improve change detection performance and verify this improvement with simulated and experimental results.

9460-17, Session 5

Change detection on UGV patrols with respect to a reference tour using VIS imagery

Thomas Müller, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Autonomous driving robots (UGVs) equipped with visual-optical (VIS) cameras offer a high potential to automatically detect suspicious occurrences and dangerous or threatening situations on patrol. In order to explore this potential, the scene of interest is recorded first on a reference tour representing the ‘everything okay’ situation. On further patrols changes are detected with respect to the reference in a two step processing scheme. In the first step, an image retrieval is done to find the reference images that are closest to the current camera image on patrol. This is done efficiently based on precalculated image-to-image registrations of the reference by optimizing image overlap in a local reference search (after a global search when that is needed). In the second step, a robust spatio-temporal change detection is performed that widely compensates 3-D parallax according to variations of the camera position. Various results document the performance of the presented approach.

9460-18, Session 6

Pressing the sparsity advantage via data-based decomposition

Vahid R. Riasati, Laura Andress, Raytheon Space & Airborne Systems (United States); Denis Grishin, Rockwell Collins (United States)

The l1-norm reconstruction techniques have enabled exact data reconstruction with high probability from ‘k-sparse’ data. This paper presented an added technique to press this reconstruction by truncating the

sparse data in its decomposed state. The truncation utilizes a transformation of the eigen-vectors of the covariance matrix and prioritizes the vectors equally without regard to their energy levels associated to the eigen-values of the vectors. This method presents two primary advantages in data representation: first, the data is naturally represented in only a few terms components of each of the vectors, and second, the complete set of features is represented, albeit, the fidelity of the representation may have changed. This technique alleviates the issues associated with high-energy fading of small-signal data features. The current technique utilizes the natural contributions of various frequencies associated with each signal sample in the eigen-vector data representation enabling a high probability of exact reconstruction of the vectors using very few samples.

9460-19, Session 6

Orthomosaic construction and analysis of EO imagery from a small unmanned aircraft system (SUAS) for natural resources management on an active military training range

Leslie Bolick, Nicholas C. Stroumtsos, Dawn Lawson, Kimberly O'Connor, SPAWAR Systems Ctr. (United States)

Small Unmanned Aircraft Systems (SUAS) provide remote sensing platforms that offer efficient deployment and ultra-high spatial resolution data well suited to focused surveys. These systems have particular value for natural resources management (NRM) on military installations, where monitoring is required for regulatory compliance but ground access is constrained by training activities, challenging terrain, and unexploded ordnance (UXO). US Pacific Fleet (PACFLT) has initiated a UAS remote sensing program for NRM at San Clemente Island (SCI), a military training range and ship-to-shore live firing range with ten federally listed endangered or threatened species regulated by the US Fish and Wildlife Service (USFWS). PACFLT aims to improve management of these species in order to reduce encumbrances on the Navy, while also reducing NRM program costs and training mission conflicts by expanding remote sensing coverage in training areas using SUAS. The first mission was flown with the Aeryon Sky Ranger, a quadcopter equipped with a stabilized EO camera, tasked with collecting imagery across known locations of SCI Bushmallow, a federally listed endangered plant whose population status in the Shore Bombardment Area (SHOBA) was unknown. EO imagery collection, orthomosaic construction, 3D terrain modeling, and image classification provided direct quantification of SCI bushmallow population distributions in SHOBA that meet USFWS monitoring requirements and can be used to support delisting and recovery. Based on the success of the first mission, new applications in UAS remote sensing for NRM are currently under development including invasive weed species detection and monitoring, wildlife population assessment and predator control.

9460-20, Session 7

Context and quality estimation in video for enhanced event detection

John M. Irvine, Richard J. Wood, Draper Lab. (United States)

Numerous practical applications for automated event recognition in video rely on analysis of the objects and their associated motion, i.e., the kinematics of the scene. The ability to recognize events in practice depends on accurate tracking objects of interest in the video data and accurate recognition of changes relative to the background. Numerous factors can degrade the performance of automated algorithms. Our object detection and tracking algorithms estimate the object position and attributes within the context of a dynamic assessment of video quality, to provide more reliable event recognition under challenging conditions. We present an approach to robustly modeling the image quality which informs tuning parameters to use for a given video stream. The video quality model rests on a suite of image metrics computed in real-time from the video. We will describe the formulation of the image quality model. Results from a recent experiment will quantify the empirical performance for recognition of events of interest.

9460-21, Session 7

Image sequence exploitation for mobile operations

Markus Mueller, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany); Stella Oldenbuerger, Bundeswehr Technical Ctr. for Information Technology and Electronics (Germany)

Unmanned Aerial Systems (UAS) are equipped with various electro-optical (and other) sensors for reconnaissance and surveillance tasks. These systems play an important role in international peacekeeping missions, armistice surveillance, defense against terrorism, disaster relief, and other sovereign tasks. Therefore, the Fraunhofer IOSB developed in close cooperation with the Technical Center of the German Armed Forces the generic and integrative platform for automatic and semiautomatic image sequence exploitation ABUL (Automated Image Exploitation for UAS). Since the system deals with live video/image sequences, real-time requirements demand efficient implementations. One core topic is the registration of two or more images of a sequence or of different sensors in real-time and in high quality. The estimated registration parameters allow for further processing like image stabilization, panorama composition, image mosaicking, image-based moving target detection, 3D-model extraction/fitting, target recognition and target distance estimation. Although originally developed for the use in ground control stations further developments concern the use on mobile devices in (protected) vehicles or on personal equipment during operations. This implies that the system must be adapted to novel use cases, e.g. by developing new user interface concepts, and new system requirements, e.g. limited computing power. The paper describes recent advances with respect to system technology, high-level and real-time capable image exploitation algorithms for mobile operations.

9460-22, Session 7

Automated FMV image quality assessment based on power spectrum statistics

Andrew R. Kalukin, NGA/IID (United States)

Factors that degrade image quality in video and other sensor collections, such as noise, blurring, and poor resolution, also affect the power spectrum of imagery. Prior research from the last few decades has shown that the image power spectrum can be useful in assessing image quality in static images. The research in this article explores the possibility of using the power spectrum to automatically evaluate full-motion video (FMV) imagery frame by frame. Degradation factor effects on power spectrum are simulated in the research, and analysis of variance is applied to ascertain the ability of power spectrum statistics to measure image quality. The goal of the research will be to develop an automated system for assigning image quality ratings calibrated to the National Imagery Interpretability Rating Scale (NIIRS) modified for video products.

9460-24, Session 7

An automated analysis of wide area motion imagery for moving subject detection

David Tahmoush, U.S. Army Research Lab. (United States)

Automated analysis of wide area motion imagery (WAMI) can significantly reduce the effort required for converting data into reliable decisions. We register consecutive WAMI frames and use false-color frame comparisons to highlight possible subjects in the imagery. We then prepare and prioritize a queue of detections for automated revisit with smaller field-of-view assets based on the locations and features of the movers as well as the probability of the detection. This automated queue works within an operator's preset prioritizations but also allows the flexibility to dynamically respond to new events as well as incorporating additional information into the surveillance tasking.

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9461-1, Session 1

Calculation of the phase-center offset from 2D antenna radiation patterns

Patrick S. Deboux, Berenice Verdin, U.S. Army Research Lab. (United States); Samuel A. Pichardo, The Univ. of Texas at El Paso (United States)

Measuring the radiation pattern of a directive antenna when its phase center is not aligned with the center of rotation yields large far-field radiation phase changes, and if severe enough, can have a significant effect on the amplitude symmetry of the radiation pattern about its mainbeam direction. In this paper, we propose an algorithm to calculate the phase-center offset from point of rotation of a 2D antenna pattern. The hybrid algorithm is comprised of a combination of the two-point method to calculate the phase-center offset along the antenna mainbeam, and an antisymmetry method to calculate phase-center offset perpendicular to the mainbeam direction. The algorithm is tested on the E-plane radiation pattern of a cylindrical horn antenna calculated using the HFSS (High Frequency Structural Simulator) electromagnetic simulation engine, radiating at 5GHz. Given the separation distance of the transmit and receive antennas and the operating frequency, the developed algorithm can calculate the magnitude and direction of the phase-center offset relative to the axis of rotation to within 5%. The number of phase wraps is taken to account to mitigate the ambiguities that arise from offsets greater than one wavelength.

9461-2, Session 1

Characterization of radar cross section of carbon-fiber composite materials

Elliot J. Riley, Erik H. Lenzing, Ram M. Narayanan, The Pennsylvania State Univ. (United States)

Carbon fiber composite materials (CFC) have been used for many structural applications for decades. Their electromagnetic properties are now of great interest in the defense industry and are being quantified by recent research. This research has explored shielding effectiveness, antenna design, conductivity, reflection, and absorption properties.

The work in this paper explores the radar cross section of CFC structures. Various CFC samples were created using a wet layup method and vacuum bagging techniques. These samples were then placed in an anechoic chamber and their RCS values at normal incidence were measured. These measured values were compared to typical conductors made into the same shape as the RCS samples. All of the measurements were made in the X band frequency range.

The RCS of the CFC samples show some interesting results. The fiber direction in the CFC samples had great influence on the RCS. Theories and reasoning for the results are presented and discussed.

9461-3, Session 1

Design considerations for eye-safe single-aperture laser radars

Dmitry S. Starodubov, Torrey Pines Logic, Inc. (United States)

The design considerations for low cost, compact and efficient laser radars and ranging systems are discussed. The reviewed approach with single optical aperture allows reducing the size, weight and power of the system. Additional design benefits include improved stability, reliability and rigidity of the overall system. The proposed modular architecture provides simplified way of varying the performance parameters of the range finder product family by selecting the sets of specific illumination and detection modules. The performance operation challenges are presented. The implementation of non-reciprocal optical elements is considered. The cross talk between illumination and detection channels for single aperture design is reviewed. 3D imaging capability for the ranging applications is considered. The simplified assembly and testing process for single aperture range finders that allows to mass produce the design are discussed. The eye safety of the range finder operation is summarized.

9461-4, Session 1

Deployment of rare Earth elements (REEs) on RF sources, lasers, and EO/IR sensors

Asu R. Jha, JHA Technical Consulting Services (United States)

This paper identifies potential applications of REEs for RF sources, lasers , and EO sensors. Critical REE materials such as yttrium-iron-garnet (YIG), yttrium-aluminum-garnet (YAG), samarium cobalt and ternary materials are specified for radars, electronic warfare, lasers, and EO sensors.

9461-5, Session 1

System-on-chip architecture and validation for real-time transceiver optimization

Hernan Suarez, Yan Zhang, The Univ. of Oklahoma (United States)

New radar applications need to execute complex algorithms and process large quantity of data to generate useful information for the users. This situation has motivated the search for better processing solutions that include low-power high-performance processors, efficient algorithms, and high-speed data interfaces. In this work, hardware implementation of adaptive pulse compression and digital pre-distortion for real-time transceiver optimization are presented. They are based on a System-on-Chip architecture for a programmable and reconfigurable device. This study also evaluates the performance of the required pre-processing blocks such as digital down conversion, filtering, and traditional pulse compression which are implemented in the programmable logic side of the device. Moreover, this work justifies the importance of having dedicated coprocessors as hardware accelerator units, to speed up and improve the performance of high demanding computational tasks such matrix multiplication and matrix inversion, which are required to operate the covariance matrix. The tradeoffs between latency and hardware utilization for the implementation of the processing blocks are also presented. The system architecture takes advantage of the embedded dual-core ARM hard processor, which is interconnected with the logic resources through the high-performance AXI buses, to perform floating-point operations, control the processing blocks, and communicate with external PC through a customized software interface. The overall system functionality is simulated for real-time operations using a Ku-band transceiver tested together with a low-cost channel emulator for different types of waveforms.

9461-6, Session 1

Acceleration of generalized adaptive pulse compression with parallel GPUs

Jingxiao Cai, Yan R. Zhang, The Univ. of Oklahoma (United States)

Graphic Processing Unit (GPU) based parallel computing is an emerging and promising approach to accelerate massive real-time computations. For general adaptive pulse compression (APC), there are scenarios where a large number of range and Doppler cells are handled especially in 2D scanning, which have potentials for parallelization. Traditionally, the APC algorithms are specific combinations of various matrix manipulations and implemented in CPU-based processor architectures. For large scale APC, the nature of CPUs makes the computation less efficient. In contrast, the original graphic rendering tasks of GPUs require highly parallel architecture, which leads to better large matrix computing capability. The goal of this work is modifying existing APC algorithms to enhance parallelization, implementing such algorithms into embedded GPU platforms and achieving the acceleration given various types of radar applications.

An example system with low Space, Time and Power (SWaP) is demonstrated with NVidia CUDA technology, the revised algorithms are implemented on a System-on-Chip (SoC) platform "Jetson TK1", which is a light-weight computing solution distributed by NVidia with its peak computation power at over 300 GFLOPS per unit. In addition, the Thermal Design Power (TDP) of this board is just 5 watts and it is possible to be expanded to clusters and multiply the computing power.

9461-7, Session 2

Short-range harmonic radar: chirp waveform, electronic targets

Gregory J. Mazzaro, The Citadel (United States); Kyle A. Gallagher, The Pennsylvania State Univ. (United States); Anthony F. Martone, Kelly D. Sherbondy, U.S. Army Research Lab. (United States); Ram M. Narayanan, The Pennsylvania State Univ. (United States)

The U.S. Army Research Laboratory (ARL) is currently evaluating nonlinear ultra-wideband (UWB) radar for the detection of radio-frequency (RF) electronics. RF electronic targets, such as man-portable electronics, cannot be detected by traditional linear radar because the radar cross section of those targets 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 the evolution of nonlinear radar at ARL and recent results of short-range over-the-air harmonic radar tests. For the nonlinear radar discussed, the transmit waveform is a chirp which sweeps one frequency at constant amplitude over an ultra-wide bandwidth. The receiver captures a single harmonic of this entire chirp. From the UWB received harmonic, 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 the environment. The chirped harmonic radar concept is validated experimentally using a ridged horn antenna and off-the-shelf electronic targets.

9461-8, Session 2

Nonlinear synthetic aperture radar imaging using a harmonic radar

Kyle A. Gallagher, The Pennsylvania State Univ. (United States); Gregory J. Mazzaro, The Citadel (United States); Kenneth I. Ranney, Lam H. Nguyen, Anthony F. Martone, Kelly D. Sherbondy, U.S. Army Research Lab. (United States); Ram M. Narayanan, The Pennsylvania State Univ. (United States)

A major advantage of a harmonic radar over conventional radar is its ability to provide better discrimination between targets of interest, such as nonlinear targets and linear clutter targets. A harmonic radar is currently under development in order to detect nonlinear targets at a stand-off distance using the nonlinear approach. The processed nonlinear SAR images demonstrate the system's ability to clearly detect nonlinear targets and reject linear targets. In addition, the nonlinear radar is able to locate nonlinear targets in down-range and cross range.

9461-9, Session 2

Filter selection for a harmonic radar receiver

Kyle A. Gallagher, The Pennsylvania State Univ. (United States); Gregory J. Mazzaro, The Citadel (United States); Anthony F. Martone, Kelly D. Sherbondy, U.S. Army Research Lab. (United States); Ram M. Narayanan, The Pennsylvania State Univ. (United States)

In a harmonic radar system design, one of the most important components is the filter used to remove the self-generated harmonics by the high-power transmitter power amplifier, which is usually driven close to its 1-dB compression point. The obvious choice for this filter is a low-pass filter. Most low-pass filters are reflective devices, which operate by reflecting the unwanted high frequency signals back to the power amplifier output. In a harmonic radar, this reflection can create problems by generating additional forward distortion. This paper will discuss the issues arising from the use of reflective filters in harmonic radar design. We will show data validating the concept that frequency diplexers are more attractive in place of low pass filters to harmonic radar design since they route the reflected power away from the power amplifier output.

9461-10, Session 2

Sparse SAR imaging for stepped frequency nonlinear radar

Lam H. Nguyen, U.S. Army Research Lab. (United States); Kyle A. Gallagher, The Pennsylvania State Univ. (United States); Kenneth I. Ranney, U.S. Army Research Lab. (United States)

The Army Research Laboratory is studying the feasibility of using stepped-frequency ultra-wideband (UWB), synthetic aperture radar (SAR) for the detection of non-linear targets with harmonic frequency responses. The approach would filter out all natural clutter and man-made objects in the scene that do not have responses in the harmonic frequency bands. The resulting SAR imagery formed using this frequency band would be very sparse with only a few targets of interest. Therefore, sparse image processing would be ideal in this scenario.

In this paper, we will describe the sparse SAR imaging technique and its application to form SAR imagery in the harmonic frequency band. The radar is operating in the low frequency band (UHF and L bands) where the available spectrum is very sparse and shared by many radar and communications systems. Thus, the main objective in this sparse imaging scheme is achieving good performance using sparse frequency contents within the operating bandwidth. We will study and compare SAR imagery performance versus various sparsity levels.

9461-11, Session 3

Terrain clutter simulation using physics-based scattering model and digital terrain profile data

James Park, Air Force Research Lab. (United States); Joel T. Johnson, The Ohio State Univ. (United States); Kung-Hau Ding, Kristopher Kim, Joseph Tenbarge, Air Force Research Lab. (United States)

Clutter suppression is critical to the performance of Air Moving Target Identification (AMTI), Ground Moving Target Identification (GMTI), and other radar applications. This requires an improved understanding of radar clutter property. To understand the characteristics of terrain clutter, numerous clutter modeling approaches have been investigated using a statistically described surface or a deterministic surface. Although these approaches address the general characteristics of clutter, the impact of radar geometries, terrain types, and topographies on scattering coefficients have not been studied in detail by using physics-based EM models combined with Digital Terrain Elevation Datasets (DTED). This approach allows us to study the direct effect of terrain to be surveyed on the scattering problem to be solved. In this paper, we investigate physics-based clutter modeling approaches using DTEDs as underlying basis for terrain large scale topography. Digital terrain data with a spatial resolution at 1/9 arc is of interest to this research. A digital terrain profiles is triangulated to generate the surface facets, and line-of-sight analysis is performed to differentiate the shadowed and illuminated regions, which is critical to capturing the physics of low grazing angle terrain scattering. Furthermore, the local terrain slope of illuminated facets and the slope of rays from the ray-tracing method define the radar geometries. The size of the radar resolution cell on the ground is first calculated using the relevant radar parameters. Next the terrain surface facets can be described by the roughness parameters: rms height and correlation length to address the small-scale local terrain features. To obtain the scattering coefficient over a resolution cell, the small perturbation method (SPM), physical optics (PO), or other approximate analytical method for capturing small scale roughness returns is used.

9461-12, Session 3

Radar-centric scattering of possible targets for orbital debris remediation

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Decades of international launches and various space expeditions in the low Earth orbit (LEO) have caused it to become littered with man-made objects and debris. With over 22,000 objects larger than a softball, and hundreds of thousands in smaller size existing, remediation efforts must take place to minimize the likelihood of on-orbit debris collisions with either civilian, or military assets. While many conceptual techniques for debris remediation exist, an active form of engagement will most likely be necessary. In regards to the debris itself, smaller objects become difficult to track, and require more onboard resource consumption for engagement. Conversely, larger bodies, such as rocket bodies, offer a greater volume for removal with less required space-based operations. Robust sensor packages required to detect, track, and engage these targets would most likely include an onboard microwave remote sensing system such as Radar. To assist in the architectural design of these sensors, relevant apriori Radar-centric scattering knowledge of these large freely tumbling bodies is essential. This paper focuses on the scattering phenomenology from possible large bodied orbital debris, such as rocket bodies, whose geometries are publically available. Particular emphasis is placed on the exhaust nozzle as this is a commonly reoccurring feature between rocket configurations, which could be utilized a grappling, interlocking, or interfacing structure. Radar required, and producible, data will be analyzed with considerations for extracting the nozzle feature from the bodies themselves presented. Radar Cross Section (RCS) distributions, tumbling body analysis, and other related scattering parameters will be assessed and discussed.

9461-14, Session 3

Building detection in SAR imagery

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Current techniques for building detection in Synthetic Aperture Radar (SAR) imagery can be computationally expensive and/or enforce stringent requirements for data acquisition. We present a technique that is effective and efficient at determining an approximate building location from multi-pass single-pol SAR imagery. This approximate location provides focus-of-attention to specific image regions for subsequent processing. The proposed technique assumes that for the desired image, a preprocessing algorithm has detected and labeled bright lines and shadows. Because we observe that buildings produce bright lines and shadows with predetermined relationships, our algorithm uses a graph clustering technique to find groups of bright lines and shadows that create a building. The nodes of the graph represent bright line and shadow regions, while the arcs represent the relationships between the bright lines and shadow. Constraints based on angle of depression and the relationship between connected bright lines and shadows are applied to remove unrelated arcs. Once the related bright lines and shadows are grouped, their locations are combined to provide an approximate building location. Experimental results are presented to demonstrate the outcome of this technique.

9461-15, Session 3

Automatic segmentation of ice layers in radar images

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Global warming has caused serious damage to our environment in recent years. Accelerated loss of ice from Greenland and Antarctica has been observed in recent decades. The melting of polar ice sheets and mountain glaciers has a considerable influence on sea level rise and altering ocean currents, potentially leading to the flooding of the coastal regions and putting millions of people around the world at risk. Synthetic aperture radar (SAR) systems are able to provide relevant information about subsurface structure of polar ice sheets. Manual layer identification is prohibitively tedious and expensive and is not practical for regular, long-term ice-sheet monitoring. Automatic layer finding in noisy radar images is quite challenging due to huge amount of noise, limited resolution and variations in ice layers and bedrock. This study presents an efficient automatic algorithm to detect several layers of ice sheets using mathematical morphology operations. The proposed approach involves the identification and selection of internal layers. Experimental results of testing on publicly available SAR data of Greenland and Antarctica show promising capabilities for automatically detecting ice layers.

9461-16, Session 4

Bistatic and multistatic target identification for through-wall radar imaging

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Bistatic and multistatic antenna systems have become increasingly popular for through-wall radar imaging because of their ability to collect more target scattering information. This increased information allows for better identification of human targets in complex environments. In this paper, the use of bistatic and multistatic radar for discriminating against clutter and the general use of cross-polarization in multistatic systems is examined. To investigate the ability of radar systems in target identification, returns from common office clutter and human targets for monostatic and bistatic arrays were captured. The data were processed to construct receiver operating curves for both system and multistatic radar. Furthermore, data were gathered for a human target in different environments using both co-and cross-polarization for direct comparison. Results indicate that multistatic radar offers increased discrimination against clutter while co-polarization images targets more clearly than cross-polarization.

9461-17, Session 4

Fall detection and classification though walls and in heavy indoor clutter

Moeness G. Amin, Fauzia Ahmad, Villanova Univ. (United States)

As the field of assisted living using remote radar monitoring progresses, it has become important to examine the offerings of this technology in actual homes or elderly care facility settings. The fall and gait classifiers which proved effective in direct line-of-sight scenarios and controlled lab settings may face challenges when operating on data gathered through single and multiple walls and in presence of heavy clutter caused by resolvable and unresolvable multipath. This paper compares the performance of several fall classifiers, which extract their features from the data time-frequency representations. The data is collected in home and office environments where the radar unit is placed 1) at different heights, and 2) in different rooms. We examine the power and antenna gain necessary to sense the human gross-motor activities, specifically falls. The paper also shows the advantages of using two radar units, in lieu of a single unit, and discusses fusion strategies to reduce false alarms and avoid blind spots. In addition to falls, the experiments include sitting, standing, falling off bed, and falling off chair.

9461-18, Session 4

RCS information theoretic approach for target classification

Travis D. Bufler, Ram M. Narayanan, The Pennsylvania State Univ. (United States); Traian V. Dogaru, U.S. Army Research Lab. (United States)

This paper investigates the application of information theory for the classification of stationary human targets and indoor clutter. The paper focuses on analysis and comparison between stationary human targets and that of common indoor clutter through modeling results obtained 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 target and clutter RCS characteristics are then investigated in terms of their entropy and mutual information (MI) content. Based upon variables such as frequency, polarization, and aspect, angle a radar's waveform can be optimized to provide separation between targets and clutter. Experimental results and scenarios are used to compare and contrast target emphasis and clutter suppression via information theory.

9461-19, Session 5

Performance analysis of spectrally versatile forward-looking ground-penetrating radar for detection of concealed targets

Brian R. Phelan, The Pennsylvania State Univ. (United States); Marc A. Ressler, Kenneth I. Ranney, Gregory D. Smith, Getachew A. Kirose, Kelly D. Sherbondy, U.S. Army Research Lab. (United States); Ram M. Narayanan, The Pennsylvania State Univ. (United States)

Stepped-Frequency Radars (SFR) have become increasingly popular with advent of new technologies and increasingly congested RF spectrum. Furthermore, SFRs have inherently high dynamic range due to their small IF bandwidths, allowing for the detection of weak target returns in the presence of clutter. The Army Research Laboratory's (ARL) Partnership in Research Transition (PIRT) program has developed a preliminary SFR for imaging buried landmines and Improvised Explosive Devices (IEDs). The preliminary system utilizes 2 transmit antennas and 4 receive antennas and is meant to act as a transitional system to verify the system's design and imaging capabilities. The SFR operates between 300 MHz and 2000 MHz, and is capable of 1-MHz step-sizes. A 16-receive channel system is anticipated to supersede the preliminary system, this system will be mounted on ARL's existing Forward-Looking Ground Penetrating Radar (FLGPR) platform which was used for the Synchronous Impulse REconstruction (SIRE) radar. An analysis of the preliminary SFR's RFI mitigation, dynamic range, clutter rejection, and imaging capability is presented here.

9461-20, Session 5

FlexSAR: demonstrating high-quality, cost-effective multimodal radar system prototyping

Mark D. Jensen, Chad Knight, Space Dynamics Lab. (United States)

The FlexSAR radar system was designed to be a high quality, low-cost, flexible, research prototype instrument. Radar researchers and practitioners often desire the ability to prototype new or advanced configurations, yet the ability to enhance or upgrade existing radar systems can be cost prohibitive. A flexible radar system that can be easily extended with minimal cost and time expenditures could drastically reduce the resources required for developing and validating advanced radar modalities. The FlexSAR system is designed to achieve such extensible, flexible capabilities. This is accomplished by using an RF design that leverages connectorized components with digital COTS cards in a PC. The connectorized RF design allows for efficient RF configuration such as increasing the bandwidth, center-frequency, etc. The digital COTS cards provide software defined radio (SDR) capability. Adding channels (RX or TX) is easily accomplished by incorporating additional digital COTS cards. The PC allows for a cost-effective storage device, incorporating raided SSD drives to capture raw or processed data. This is beneficial because the ability to capture raw data can be desirable for real-time algorithm development and validation. A more detailed design consideration (advantages and disadvantages) is discussed and multiple examples of the flexible system nature of the FlexSAR system are illustrated for diverse applications including multi-band SAR (L/X), quad-polarizations (littoral), and ATI (GMTI/SAR) applications. The RF and digital configuration is modified for the various applications. The required changes are discussed as well as the overall system performance for each application.

9461-21, Session 5

Recent experiments using the ARL Rail-SAR

Kenneth I. Ranney, U.S. Army Research Lab. (United States); Brian R. Phelan, The Pennsylvania State Univ. (United States); Getachew A. Kirose, Kelly D. Sherbondy, U.S. Army Research Lab. (United States)

The Army Research Laboratory has constructed an indoor, rail-mounted, synthetic aperture radar (SAR) system capable of simulating airborne data collection geometries. The collection facility includes both a "building within a building" for through-the-wall measurements and a "sand pit" for buried-target measurements. While we collect background measurements for the purpose of clutter removal, the elimination of multi-path responses due to target emplacements presents a significant problem. These multipath effects can manifest themselves as artifacts in the processed SAR imagery—artifacts that were observed in data presented at last year's Defense, Security and Sensing Radar Sensor Technology conference. In this paper, we present the results of additional data collections and analysis performed to identify the source of observed Rail-SAR artifacts. We describe the procedures developed to eliminate artifacts in future Rail-SAR experiments and analyze data collected using various target emplacement scenarios. We examine results obtained both with and without the new measurement procedures in place.

9461-22, Session 5

Technology integration and synergies: radar, optics, and AIS

Hasan Shahid, Stevens Institute of Technology (United States); Joe Nathan Abellard, New York City College of Technology (United States); Yong-Qi Chen, Stevens Institute of Technology (United States); David M. González Chévere, Univ. de Puerto Rico Mayagüez (United States)

Various technologies were used to detect, track, and classify vessels on the Hudson River. Broadband radar was used to detect and track vessels. Visible light cameras, infrared cameras, and image processing techniques were used to detect, track, and classify vessels. Automatic Identification System (AIS) was used to track and classify vessels. The technologies, collectively referred to as the Integrated Technology System (ITS), were used in conjunction with each other to achieve synergies and to overcome individual system limitations. These limitations included a narrow field of view, faulty detection and poor classification capabilities. Over the course of six weeks, the ITS was used to observe vessel traffic on the Hudson River in order to test the effectiveness of the system. The suite of technologies successfully fulfilled its purpose. The radar was effective despite some errors. The cameras allowed for software development including automatic slewing and image processing. While AIS was considered the most reliable tool, it was determined not to be infallible. Future work includes integration of passive acoustics into the system and wake analysis for vessel detection.

9461-23, Session 5

Radom effects on coherent change detection radar systems

Ann M. Raynal, Dale F. Dubbert, Bryan L. Burns, William H. Hensley Jr., Sandia National Labs. (United States)

A radome, or radar dome, protects a radar system from exposure to the elements. Unfortunately, radomes can affect the radiation pattern of the enclosed antenna. The co-design of a platform's radome and radar is ideal to mitigate any deleterious effects of the radome. However, maintaining structural integrity and other platform flight requirements, particularly when integrating a new radar onto an existing platform, often limits radome electrical design choices. Radars that rely heavily on phase measurements such as monopulse, interferometric, or coherent change detection (CCD) systems require particular attention be paid to components, such as the radome, that might introduce loss and phase variations as a function of the antenna scan angle. Material properties, radome wall construction, overall dimensions, and shape characteristics of a radome can impact insertion loss and phase delay, antenna beamwidth and sidelobe level, polarization, and ultimately the impulse response of the radar, among other things, over the desired radar operating parameters. The precision-guided munitions literature has analyzed radome effects on monopulse systems for well over half a century. However, to the best of our knowledge, radome-induced errors on CCD performance have not been described. The impact of radome material and wall construction, shape, dimensions, and antenna characteristics on CCD is examined herein for select radar and radome examples using electromagnetic simulations.

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9461-24, Session 5

SAR-based vibrometry using the fractional Fourier transform

Majeed M. Hayat, The Univ. of New Mexico (United States); Tom D. Atwood, Sandia National Labs. (United States); Justin B. Campbell, Jelili Ade-bello, Ishwor Bhatta, Humberto Caudana, Nicole B. Trujillo, Balu Santhanam, Walter H. Gerstle, The Univ. of New Mexico (United States); Armin W. Doerry, Sandia National Labs. (United States)

Theoretical and experimental research in the past few years by the group at the University of New Mexico has demonstrated that a single synthetic-aperture-radar (SAR) platform can serve in performing the simultaneous generation of imagery and the corresponding vibration histories of the objects being imaged at each pixel. The vibrometry approach is based upon a powerful signal-analysis technique, called the fractional Fourier transform (FRFT), which enables the production of three-dimensional data comprising the vibration histories (acceleration, velocity and amplitude) co-registered with a SAR image. In this presentation, we will show the potential for extending this SAR-based capability to remotely detect and classify objects that are housed inside buildings and other cover based knowing the location of vibrations as well as the vibration histories of the vibrating structures that house the vibrating objects. This presentation specifically includes simulation and certain experimental results (using the Lynx SAR System in collaboration with General Atomics - ASI) of SAR imagery and the vibration histories of a certain structure that is designed and built by our group to serve as a test target. The sensed vibration histories are compared with the ground truth, which is obtained from accelerometers attached to both the vibrating objects inside the structure as well as the vibrations of the surface of the housing structure. Preliminary recommendations on the detectable vibration frequency and amplitude, as well as the required radar-cross-section and signal-to-clutter ratio will be presented.

9461-25, Session 6

An algorithm for segmenting polarimetric SAR imagery

Jorge V. Geaga, Consultant (United States)

We have developed an algorithm for segmenting fully polarimetric single look TerraSAR-X, multilook SIR-C and 7 band Landsat 5 imagery using neural nets. The algorithm uses a feedforward neural net with one hidden layer to segment different surface classes. The weights are refined through an iterative filtering process characteristic of a relaxation process. Features

selected from studies of fully polarimetric complex single look TerraSAR-X data and multilook SIR-C data are used as input to the net. The seven bands from Landsat 5 data are used for as input for the Landsat neural net. The Cloude-Pottier incoherent decomposition is used to investigate the physical basis of the polarimetric SAR data segmentation. The segmentation of a SIR-C ocean surface scene into four classes will be presented.

9461-26, Session 6

Generalization of susceptibility of RF systems through far-field pattern superposition

Berenice Verdin, Patrick S. Debroux, U.S. Army Research Lab. (United States)

The purpose of this paper is to perform an analysis of RF (Radio Frequency) communication systems in an extensive electromagnetic environment to identify its susceptibility to jamming systems. We propose a new method that incorporates the use of reciprocity and superposition of the far-field radiation pattern of the RF system Fr(φr,θr) and the far-field radiation pattern of the jammer system Fj(φj,θj). By using this method we can find the susceptibility pattern of RF systems with respect to the elevation and azimuth angles Fs(φs,θs). An experiment was performed with HFSS (High Frequency Structural Simulator) where the radiation pattern of the jammer was simulated as a cylindrical horn antenna. The RF receiver antenna used was a half-wave dipole inside a cavity with apertures that approximates a land-mobile vehicle. Because of the limitation of the simulation method, extensive electromagnetic environments cannot be quickly simulated in HFSS. Therefore, the combination of the transmit antenna radiation pattern superimposed onto the receive antenna pattern was performed in MATLAB. A 2D or 3D susceptibility area is obtained with respect to the azimuth and elevation angles. In addition, by incorporating the jamming equation into this algorithm, the received jamming power at the RF receiver Pr(φr,θr) can be calculated. The received power depends on antenna properties, propagation factor and system losses. Test cases include: a cavity with four apertures, a cavity above an infinite ground plane, and antennas with vertical and horizontal polarizations. By using the proposed algorithm a susceptibility analysis of RF systems in electromagnetic environments can be performed.

9461-27, Session 6

A practical look at target detection using MIMO radar

Mark A. Govoni, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States); Jeffrey Spak, U.S. Army Communications-Electronics Research Development and Engineering Command (United States); Traian V. Dogaru, DaHan Liao, U.S. Army Research Lab. (United States)

The conditions for orthogonality in Multiple Input Multiple Output (MIMO) radar enable a virtual array gain beneficial to beamforming on receive. However, this condition imposes a constraint on the transmit beam since the aperture is non-coherently formed across the real array. As such, both the antenna gain and the effective radiated power suffer when compared to a traditional monostatic phased array. With this in mind, we will investigate the expected receive power for a scenario in which MIMO radar beamforming is used to illuminate an arbitrary target-of-interest (TOI) obfuscated by different line-of-sight (LOS) obstructions such as foliage and/or buildings. Using finite-difference time-domain (FDTD) modeling, our simulations will grow the understanding of how plausible MIMO radar is for detecting targets in challenging environments.

9461-28, Session 6

Reflection RF tomography of stationary objects in free space: preliminary results

Jia Li, Oakland Univ. (United States); Robert L. Ewing, Charles Berdanier, Air Force Research Lab. (United States); Chris J. Baker, The Ohio State Univ. (United States)

RF tomography has great potential in defense and homeland security applications. A distributed sensing research facility is under development at Wright Patterson air force base. It is consisted of 12 radar sensors located on a ring of 100 meter radius in a near urban environment. To develop a RF tomographic imaging system for the facility, preliminary experiments have been performed in an indoor range with the same sensor set up scaled down to a ring of 3m radius. Ultra-wideband pulses of 10GHz bandwidth were used to illuminate single and multiple spherical targets. The echoes received by distributed sensors were processed and combined to reconstruct the tomography. Traditional matched filter algorithm and truncated singular value decomposition algorithm are compared in terms of their complexity, accuracy, and suitability for distributed processing. The main contribution of our work is a new algorithm, which jointly estimates the scatter points on the waveform's propagation path and the object boundary. In the experiments, the 12 radar sensors are non-uniformly distributed on the ring and direct path coupling is the main clutter. To effectively mitigate direct path coupling and reject clutters in the field, sensor data are weighted and fused according to the relative location and orientation of transmitter and receiver pairs. The results show that the new algorithm allows accurate reconstruction of the object shape, which is not available through the traditional algorithms.

9461-29, Session 6

Application of equalization notch to improve synthetic aperture radar coherent data products

Cameron Musgrove, Sandia National Labs. (United States); James C. West, Oklahoma State Univ. (United States)

Interference and interference mitigation techniques degrade synthetic aperture radar (SAR) coherent data products. Radars utilizing stretch processing present a unique challenge for many mitigation techniques because the interference signal itself is modified through stretch processing from its original signal characteristics. Many sources of interference, including constant tones, are only present within the fast-time sample data for a limited number of samples, depending on the radar and interference bandwidth. Adaptive filtering algorithms to estimate and remove the interference signal that rely upon assuming stationary interference signal characteristics can be ineffective. An effective mitigation method, called notching, forces the value of the data samples containing interference to zero. However, as the number of interference sources increase and the number of data samples set to zero increases, image distortion and loss of resolution degrade both the image product and the coherence data products.

Techniques to repair image distortions, such as CLEAN, are effective in certain cases for point-like targets. However, CLEAN is unable to model and repair distortions within SAR image terrain. Good terrain coherence is important for most SAR images because terrain occupies the majority of the image. For the case of coherence change detection it is the terrain coherence itself that determines the quality of change detection image.

This paper proposes a unique equalization technique that improves coherence over existing notching and equalization techniques. First, the proposed algorithm limits mitigation to only the samples containing interference, unlike filtering algorithms, so that the remaining samples maintain maximum coherence from pass to pass. Additionally, the mitigation adapts to changing interference power such that the resulting correction equalizes the power across the data samples. The result is reduced distortion and improved coherence for the terrain. Simulated and real SAR data demonstrate improved coherence from the proposed equalization correction over existing notching and equalization methods for chirped interference sources.

9461-30, Session 7

Radar cross-sectional study using noise radar

Al Freundorfer, Queen's Univ. (Canada); Jawad Y. Siddiqui, Yahia M. Antar, Royal Military College of Canada (Canada)

A noise radar system is proposed with capabilities to measure and acquire the radar cross-section (RCS) of targets.

The proposed system can cover a noise bandwidth of near DC to 50 GHz. The noise radar RCS measurements were conducted for selective targets like spheres and carpenter squares with and without dielectric bodies for a noise band of 400MHz-5000MHz.

The bandwidth of operation was limited by the multiplier and the antennae used.

9461-31, Session 7

Principle and experimental results of ultra-wideband noise radar imaging of a cylindrical conducting object using diffraction tomography

Hee Jung Shin, Mark A. Asmuth, Ram M. Narayanan, The Pennsylvania State Univ. (United States); Muralidhar Rangaswamy, Air Force Research Lab. (United States)

In this paper, the principle, measurement system, and experimental results of tomographic imaging of a cylindrical conducting object using random noise waveforms are presented. Theoretical analysis of scattering and the image reconstruction technique are developed based on physical optics approximation and Fourier diffraction tomography, respectively. The bistatic radar system is designed to transmit multiple independent and identically distributed (iid) ultra-wideband random noise waveforms at a fixed position, and a linear scanner allows a single receiving antenna to move along a horizontal axis for backward scattering measurement in the frequency range from 8 GHz to 10 GHz. The reconstructed tomographic image of the cylindrical conducting object based on experimental results are shown in good agreement with the simulation results, which demonstrate the capability of ultra-wideband noise radar for two-dimensional tomographic image of a cylindrical conducting object.

9461-32, Session 7

Design and implementation of a noise radar tomographic system

Mark A. Asmuth, Hee Jung Shin, Ram M. Narayanan, The Pennsylvania State Univ. (United States); Muralidhar Rangaswamy, Air Force Research Lab. (United States)

A hardware system has been developed to perform noise radar tomography at 8-10 GHz. The system utilizes RF hardware to transmit of multiple independent and identically distributed ultra-wideband random noise waveforms. A 2-4 GHz frequency band limited signal is generated using an arbitrary waveform generator and a RF system mixes the frequency up to 8-10 GHz and amplifies the waveform. A linear scanner with a single antenna is used in place of an antenna array to collect backscatter. The backscatter is collected from the transmission of each waveform and reconstructed into an image. The images that result from each scan are averaged to produce one tomographic image of the target. After background subtraction the scans are averaged to improve the image quality. The experimental results are compared to the theoretical prediction. The system has successfully imaged a PEC cylinder.

The arbitrary waveform generator allows for the production of a band limited Gaussian waveform from 0-6 GHz. This system utilizes a 2-4 GHz band limited waveform. The waveform produced by the arbitrary waveform generator is then filtered and mixed up to the target frequency of 8-10 GHz. The waveform is amplified before being transmitted through a horn antenna that is centered in front of the target object. The test object is located in front of a wall of foam absorbers. A linear scanner with a horn antenna collects the backscatter from the test object. The waveform is then mixed down to 2-4 GHz and time domain data is taken with an oscilloscope. The data are then used to reconstruct a tomographic image of the test object. The images from each iid ultra-wideband random noise waveform are then averaged together.

9461-33, Session 7

Efficient pulse compression for LPI waveforms based on a nonparametric iterative adaptive approach

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In order to achieve low probability-of-intercept, LPI waveforms are usually long and randomly generated. Due to the randomized nature, Matched filter responses (autocorrelation) of those waveforms can have high sidelobes which would mask weaker targets near a strong target, limiting radar's ability to distinguish close-by targets. To improve resolution and reduced sidelobe contaminations, a waveform independent pulse compression filter is desired. Furthermore, the pulse compression filter needs to be able to adapt to received signal to achieve optimized performance. As many existing pulse techniques require intensive computation, real-time implementation is infeasible. This paper introduces a new adaptive pulse compression technique for LPI waveforms that is based on a nonparametric iterative adaptive approach (IAA). Unlike the original IAA filter that is designed to operate directly on the received signal, the proposed approach uses matched filter outputs as its input, thus termed MF-IAA filter. Since the length of the MF-IAA filter can be very small compared to the transmitted waveform, it is more efficient than the original IAA. Also due to the nonparametric nature, no parameter tuning is required for different waveforms. Furthermore, as MF has been implemented in many existing radar systems, the MF-IAA filter may be applied without significant modification. A general requirement analysis for future pulse compression radar sensing is provided, followed by detailed derivation of the proposed MF-IAA filter. The proposed algorithm is tested with some typical LPI waveforms and its performance is discussed and compared with other APC techniques. It is shown that the MF-IAA filter is efficient, robust, and can is truly waveform-independent.

9461-34, Session 7

Probability of target detection using advanced pulse compression noise (APCN)

Mark A. Govoni, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States); Ryan A. Elwell, U.S. Army Communications-Electronics Research Development and Engineering Command (United States); Traian V. Dogaru, DaHan Liao, U.S. Army Research Lab. (United States)

The advanced pulse compression noise (APCN) radar waveform preserves salient features from both traditional pulse compressed and stochastic waveforms. Having the ability to control the waveform features by automated tuning of the amplitude and phase control parameters allows the user to optimize radar system performance as a function of the channel conditions. Given the typical dependencies of radar cross-section (RCS), we will investigate the e?ects that waveform tuning, specifically non-uniform transmit envelope have on classic radar detection for cases when di?erent line-of-sight (LOS) scenarios are considered. Using finite-di?erence time-domain (FDTD) modeling, our simulations will grow the understanding of how plausible cognitive waveforms such as APCN are for detecting targets under various conditions.

9461-35, Session 8

Analysis of chaotic system synchronization for bistatic radar

Chandra S. Pappu, The Univ. of Texas at El Paso (United States); Berenice Verdin, U.S. Army Research Lab. (United States); Benjamin C. Flores, The Univ. of Texas at El Paso (United States); James Boehm, Patrick S. Debroux, U.S. Army Research Lab. (United States)

We propose a scheme for bistatic radar that uses a chaotic system to generate a wideband signal that is replicated at the receiver to extract high resolution information from targets. The setup for the bistatic radar includes an n state variable drive oscillator at the transmitter and a response oscillator at the receiver. A challenge for this setup resides in synchronizing the response oscillator of the radar receiver utilizing a scaled version of the transmitted signal sr(t, x) = αst(t, x) where x is a drive oscillator state variables and α is the scaling factor that accounts for antenna gain, system losses, and space propagation. For AM, we assume that the transmitted signal is an amplified version of the state variable x: st(t)= Ax(t). Likewise, the received signal is sr(t) = αx(t). Since α is not known a priori, the response oscillator must be able to accept the scaled version of x as an input. Thus, we utilize a generalized projective synchronization technique proposed by Yan and Li that introduces a controller variable μ(xs – αx) into the Lorenz system, where xs is the response state variable and α is a controller parameter and show that the synchronization is achievable for α ≥ 10–4. For FM, demodulation of sr(t) is required to reconstruct the chaotic state variable x for oscillator synchronization. We verify through simulations that, once synchronization is achieved, the short-time correlation of x and xs is high and that this correlation is consistent over long periods of time.

9461-36, Session 8

The implementation of compressive sensing on an FPGA for chaotic radars

Hector A. Ochoa, The Univ. of Texas at Tyler (United States); David H. Hoe, Loyola Univ. Maryland (United States); Dinesh Veeramachaneni, The Univ. of Texas at Tyler (United States)

Most of the advances in current radar systems are aimed at improving their resolution [1] [2] [3]. As a result, their operating frequency has been increased from 10GHz up to 94GHz, and new millimeter-wave (100-300GHz) radar systems are currently being studied. One of the major concerns with these frequencies is the associated large bandwidth requirement. Compressive Sensing (CS), also known as Compressive Sampling, has been proposed as a solution to overcome the aforementioned problems by exploiting the sparsity of the radar signal [4] [5] [6] [7] [8] [9]. Using the CS method, a sparse signal can be reconstructed even if it is sampled below the Nyquist rate. This method provides a completely new way to reconstruct the signal using optimization techniques and a minimum number of observations. The objective of this research project is to investigate and develop a Chaotic Radar Imaging system that leverages Compressive Sensing [10] [11] (CS) technology to improve the image resolution without increasing the amount of processed data. In addition to demonstrating the validity of the proposed approach through simulations, this project seeks to develop and implement hardware prototypes for the proposed imaging radar system. Simulated chaotic radar data was generated and loaded to the FPGA board to test the algorithms and their performance. The results from implementing the Orthogonal Matching Pursuit (OMP) and the Stage wise Optimal Matching Pursuit (STOMP) algorithms to an FPGA will be presented.

9461-37, Session 9

Range detection using entangled optical photons

Matthew J. Brandsema, Ram M. Narayanan, The Pennsylvania State Univ. (United States); Marco O. Lanzagorta, U.S. Naval Research Lab. (United States)

Quantum Radar is a developing field that shows a lot of promise in providing much more resolution than its classical radar counterpart. The key to this kind of resolution lies in the entanglement of the photons being used.

In this paper, the basic concepts of a quantum radar are briefly discussed. This includes the fundamental concepts of what a quantum radar is, as well as some of the engineering challenges into making one with the current technology available.

Proceeding that is a discussion of the experiment done in this paper using optical photons from SPDC methods. After the entangled photons are created and emerge from the crystal, the idler photon is detected very shortly after. At the same time the signal photon is sent out towards the target and upon its reflection will impinge on the detector of the radar. From these two measurements, correlation data processing is done to achieve the distance of the target away from the radar. Various simulations are then shown to display the resolution that is possible.

Lastly, experimental results of the actual experiment are shown, along with a discussion of the implications of these results. Although the ideal quantum radar will be built in the microwave regime, the information from this study are still extremely important to show the feasibility of the system, and the types of measurements that need to be done.

9461-38, Session 9

Algorithmic analysis of quantum radar sidelobes

Salvador E. Venegas-Andraca, Tecnológico de Monterrey (Mexico); Marco O. Lanzagorta, U.S. Naval Research Lab. (United States)

Sidelobe structures on classical radar cross section graphs are a consequence of discontinuities in the surface currents. In contrast, quantum radar theory states that sidelobe structures on quantum radar cross section graphs are due to quantum interference. Moreover, it is conjectured that quantum sidelobe structures may be used to detect targets oriented off the specular direction [1].

Algorithmic modeling of physical phenomena is one of the goals of quantum computing. Quantum walks, a universal model of quantum computation, is a powerful tool for modeling physical processes in which quantum interference is involved [2].

Because of the high data bandwidth expected from quantum radar, it may be necessary to use sophisticated quantum signal analysis algorithms to determine the presence of stealth targets through the sidelobe structures. In this paper we introduce a quantum walk-based algorithmic description of quantum sidelobe structures. It is our purpose to develop a computer science-oriented tool for further physical analysis of quantum radar models as well as applications of quantum radar technology in various fields.

[1] Quantum Radar. Marco Lanzagorta. Morgan and Claypool (2012).

[2] Quantum Walks: a Comprehensive Review. Salvador E. Venegas-Andraca. Quantum Information Processing, vol. 11(5), pp. 1015-1106 (2012).

9461-39, Session 9

Low-brightness quantum radar

Marco O. Lanzagorta, U.S. Naval Research Lab. (United States)

One of the major scientific thrusts from recent years has been to try to harness quantum phenomena to dramatically increase the performance of a wide variety of classical information processing devices. These advances in quantum information science have had a considerable impact on the development of standoff sensors such as quantum radar. In this paper we analyze the theoretical performance of low-brightness quantum radar that uses entangled photon states. We use the detection error probability as a measure of sensing performance and the interception error probability as a measure of stealthiness. We compare the performance of quantum radar against a coherent light sensor (such as lidar) and classical radar. In particular, we restrict our analysis to the performance of low-brightness standoff sensors operating in a noisy environment. We show that, compared to the two classical standoff sensing devices, quantum radar is stealthier, more resilient to jamming, and more accurate for the detection of low reflectivity targets.

9461-40, Session 9

Quantum error reduction without coding

Keye Martin, U.S. Naval Research Lab. (United States)

No Abstract Available

9461-41, Session 9

Space-based quantum sensing for detection of small targets

Jeffrey K. Uhlmann, George Mason Univ. (United States); Marco O. Lanzagorta, U.S. Naval Research Lab. (United States)

No Abstract Available

9461-49, Session PSTue

Spurious effects of analog-to-digital conversion nonlinearities on radar range-Doppler maps

Armin W. Doerry, Dale F. Dubbert, Bert L. Tise, Sandia National Labs. (United States)

Radar operation, particularly Ground Moving Target Indicator (GMTI) radar modes, are very sensitive to anomalous effects of system nonlinearities. These throw off harmonic spurs that are sometimes detected as false alarms. One significant source of nonlinear behavior is the Analog to Digital Converter (ADC). One measure of its undesired nonlinearity is its Integral Nonlinearity (INL) specification. We examine in this paper the relationship of INL to GMTI performance.

9461-50, Session PSTue

Balancing radar receiver channels with commutation

Armin W. Doerry, Sandia National Labs. (United States)

When multiple receiver channels are employed in a pulse-Doppler radar, achieving and maintaining balance between the channels is problematic. In some circumstances the channels may be commutated to achieve adequate balance. Commutation is the switching, trading, toggling, or multiplexing of the channels between signal paths. Commutation allows modulating the imbalance energy away from the balanced energy in Doppler, where it can be mitigated with filtering.

9461-51, Session PSTue

Comments on radar interference sources and mitigation techniques

Armin W. Doerry, Sandia National Labs. (United States)

Radar ISR does not always involve cooperative or even friendly environments or targets. The environment in general, and an adversary in particular, may offer numerous techniques to diminish the effectiveness of a radar ISR sensor. These generally fall under the banner of jamming, spoofing, or otherwise interfering with the EM signals required by the radar sensor. Consequently mitigation techniques are often prudent to retain efficacy of the radar sensor. We discuss in general terms a number of mitigation techniques.

9461-52, Session PSTue

Balancing I/Q data in radar range-Doppler images

Armin W. Doerry, Sandia National Labs. (United States)

It has become the norm for modern high-performance radar systems to sample and digitize the raw radar returns for subsequent processing by Digital Signal Processing (DSP) techniques. Furthermore, the data is often rendered to distinguish between positive and negative frequencies necessitating complex data values, with real and imaginary constituents typically termed In-phase (I) and Quadrature (Q) elements respectively. However, the reality of non-ideal component and circuit behavior will allow deleterious imbalances to manifest between I and Q data elements. A number of techniques may be employed to mitigate the effects of I/Q imbalance. These are presented, as well as recommendations for new designs, as well as retrofits to existing hardware.

9461-53, Session PSTue

Joint estimation of thermal and multiplicative noise levels in dual- and quad-polarization SAR images

Robert Riley, Sandia National Labs. (United States)

An estimate of the combined thermal and multiplicative noise levels within a SAR image is sometimes required for exploitation processing and quality assessment. Given pertinent and accurate radar parameters, it is a straightforward process to estimate the thermal noise-equivalent return in a SAR image. However, the backscatter-dependent multiplicative noise level cannot be estimated a priori; furthermore, the resulting multiplicative noise level within a SAR image will in general be spatially varying in a non-trivial fashion. This paper describes a data-driven method for robustly estimating the thermal and multiplicative noise-equivalent return within a SAR image using the joint observations of dual-polarization measurements. The net cross-polarized response from a scene is typically many orders of magnitude lower than that of the co-polarized response, and hence will have an equivalent noise return that much more closely approaches that of thermal noise, while the corresponding non-return regions within the co-polarized image will exhibit substantially higher no-return magnitude. Also, true non-backscatter observations, in particular from shadows, are non-return for both the co-polarized and cross-polarized radar channels. This process does assume a modicum of non-return regions exist within

the image, but does not require finding these non-return locations. A two-dimensional co-/cross-pol joint SAR image magnitude distribution is formed, with the lowest joint magnitude density cluster representing the non-return observations within the SAR image. This process can be extended to fully-polarimetric data sets, with additional robustness being provided in that situation.

9461-54, Session PSTue

Experimental evaluation of single-aperture range finder

Kyle McCormick, Dmitry S. Starodubov, Leo Volfson, Torrey Pines Logic, Inc. (United States)

Single aperture range finders with eye safe lasers due to their smaller size and simplified design have a strong potential for wide implementation in military and commercial systems. In this paper we present the results of experimental evaluation of a single aperture laser range finder. The new design operates at eye safe wavelength range around 1535 nm and uses passively Q switched laser for illumination. The optical circulator is used to separate the detection and illumination channels. The measurements of the power budget and ranging performance evaluation for the new design are discussed.

9461-55, Session PSTue

Coherence model for building layover in interferometric SAR

Douglas L Bickel, Sandia National Labs. (United States)

The complex coherence function describes information that is necessary to create maps from interferometric synthetic aperture radar (InSAR). This coherence function is complicated by building layover. This paper presents a mathematical model for this complex coherence in the presence of building layover and shows how it can describe intriguing phenomena observed in real interferometric SAR data.

9461-76, Session PSTue

Instantaneous, stepped-frequency, nonlinear radar

Kenneth I. Ranney, U.S. Army Research Lab. (United States); Kyle A. Gallagher, The Pennsylvania State Univ. (United States); Kelly D. Sherbondy, Anthony F. Martone, U.S. Army Research Lab. (United States); Gregory J. Mazzaro, The Citadel (United States); Ram M. Narayanan, The Pennsylvania State Univ. (United States)

Researchers have recently developed radar systems capable of exploiting non-linear target responses to precisely locate targets in range. These systems typically achieve the bandwidth necessary for range resolution through transmission of either a stepped-frequency or chirped waveform. The second harmonic of the reflected waveform is then analyzed to isolate the non-linear target response. In other experiments, researchers have identified certain targets through the inter-modulation products they produce in response to a multi-tone stimulus. These experiments, however, do not exploit the phase information available in the intermodulation products.

We present a method for exploiting both the magnitude and phase information available in the inter-modulation products to create an "instantaneous" stepped frequency, non-linear target response. The new approach enables us to both maintain the unambiguous range dictated by the fundamental, multi-tone separation and obtain the entire target signature from a single transmitted waveform.

9461-80, Session PSTue

Adaptive OFDM waveform design for spatio-temporal-sparsity exploited STAP radar

Satyabrata Sen, Jacob Barhen, Oak Ridge National Lab. (United States)

We propose a sparsity-based space-time adaptive processing (STAP) algorithm to detect a slowly-moving target using an orthogonal frequency division multiplexing (OFDM) radar. The motivation of employing an OFDM signal is that it improves the target-detectability from the interfering signals by increasing the frequency diversity of the system. However, due to the addition of one extra dimension in terms of frequency, the adaptive degrees-of-freedom in an OFDM-STAP also increases. Therefore, to avoid the construction a fully-adaptive OFDM-STAP, we propose a sparsity-based STAP algorithm. We observe that the interference spectrum is inherently sparse in the spatio-temporal domain, as the clutter responses occupy only a diagonal ridge on the spatio-temporal plane and the jammer signals interfere only from a few spatial directions. Hence, we exploit that sparsity to develop an efficient STAP technique that utilizes considerably lesser number of secondary data compared to the other existing STAP techniques, and produces nearly optimum STAP performance. In addition to designing the STAP filter, we propose to optimally design the transmit OFDM signals by maximizing the output signal-to-interference-plus-noise ratio (SINR) in order to improve the STAP-performance. The computation of output SINR depends on the estimated value of the interference covariance matrix, which we obtain by applying the sparse recovery algorithm. Therefore, we analytically assess the effects of the synthesized OFDM coefficients on the sparse recovery of the interference covariance matrix by computing the coherence measure of the sparse measurement matrix. Our numerical examples demonstrate the achieved STAP-performance due to sparsity-based technique and adaptive waveform design.

9461-42, Session 10

Investigations on the effect of frequency and noise in a localization technique based on microwave imaging for an in-body RF-source

Rohit Chandra, Norwegian Univ. of Science and Technology (Norway); Ilangko Balasingham, Norwegian Univ. of Science and Technology (Norway) and Oslo Univ. Hospital (Norway)

Localization of a wireless capsule endoscope finds many clinical applications from diagnostics to therapy. There are potentially two approaches: a) model based localization using a priori information of the person's dielectric channels and, b) microwave imaging based localization without using any a priori information. In this paper we study the second approach in terms of a variety of frequencies and signal-to-noise ratios for localization accuracy and in-body RF source distance from the skin. To this end, we select a 2-D anatomically realistic numerical phantom for microwave imaging at different frequencies. The selected frequencies are 13.56 MHz, 431.5 MHz, 920 MHz, and 2.45 GHz, which are typically considered in the wireless capsule endoscopy literature. Microwave imaging of a phantom will provide us with an electromagnetic model with electrical properties (relative permittivity and conductivity) of the internal parts of the body and can be useful as a foundation for localization of an in-body RF source. Low frequency imaging at 13.56 MHz provides low resolution image with high contrast in the dielectric properties. However, at high frequencies, the imaging algorithm is able to image only the outer boundaries of the tissues due to low penetration depth as higher frequency means higher attenuation. Using these preliminary investigations, a lower frequency bound is determined with an acceptable electromagnetic tissue model having good penetration. Furthermore, a localization method based on microwave imaging is used for

estimating the localization accuracy at different frequencies and signal-to-noise ratios. Statistical evaluation of the localization error is performed using the cumulative distribution function (CDF). Based on our results, we conclude that the localization accuracy is minimally affected by the frequency or the noise. However, the choice of the frequency will become critical if the purpose is to image the internal parts of the body for tumor and/or cancer detection.

9461-43, Session 10

A new microwave imaging algorithm based on third-generation WCE system

Huiyuan Zhou, The Pennsylvania State Univ. (United States); Rohit Chandra, Norwegian Univ. of Science and Technology (Norway); Ilangko Balasingham, Oslo Univ. Hospital (Norway); Ram M. Narayanan, The Pennsylvania State Univ. (United States)

Wireless capsule endoscope (WCE) is one of the most innovative applications of wireless technology in medicine which can transmit still images and in some cases real-time video from the gastrointestinal track to an external receiver for clinical analysis and processing. The third generation WCE facilitates a transceiver inside the “pill” which operates in microwave frequency range. As a result, it can communicate with the external transceivers to provide additional information. Based on this background, a new microwave imaging algorithm needs to be developed to exploit the new transceiver in conjunction with the external transceivers in order to image the tumor under the gastrointestinal track which cannot be detected by optical images and videos. The conventional microwave tomography algorithms, such as Gauss-Newton Inversion (GNI) method and Contrast Source Inversion (CSI) method, satisfy the situation only when external antennas are included. By the introduction of the internal transmitter and receiver, this paper aims to refine the classic algorithms (GNI and CSI methods) to adapt to the new system and use numerical methods to obtain the 2-D images. We also make a comparison on how much the new system can improve the resolution of images theoretically, and furthermore use the new algorithm to detect the tumor under the surface of the gastrointestinal track.

9461-44, Session 10

Investigating signatures of diverse waveforms to assess changes in thickness and dielectric properties of intestines afflicted with Crohn’s disease

Sonny Smith, Ram M. Narayanan, The Pennsylvania State Univ. (United States); Evangelos Messaris, Penn State Milton S. Hershey Medical Ctr. (United States)

Crohn’s disease is a bowel disease resulting in inflammation along the lining of one’s digestive tract. Moreover, such an inflammatory condition causes changes in the thickness of the intestines; and we posit induce changes in the dielectric properties detectable by radar. In this paper, we consider two constitutive parameters of the intestines (i.e. thickness and relative permittivity) and scrutinize how changes in such parameters are captured by different waveforms with ultra-wideband characteristics. We extend XFDTD simulations to include various altered intestinal models and investigate the return signals of different ultra-wideband signals. Furthermore, plans are in progress to create an intestinal phantom-like model that varies in thickness and permittivity to begin laboratory measurements. Continued development in this work will lead to the design and implementation of an ultra-wide band radar system to detect and monitor Crohn’s disease.

9461-45, Session 10

Radar sensitivity to human heartbeats and respiration

Øyvind Aardal, Sverre Brovoll, Yoann Paichard, Tor Berger, Norwegian Defence Research Establishment (Norway); Tor Sverre Lande, Univ. I Oslo (Norway); Svein-Erik Hamran, Norwegian Defence Research Establishment (Norway) and Univ. I Oslo (Norway)

Human heartbeats and respiration can be detected from a distance using radar. This can be used for medical applications and human being detection. It is useful to have a system independent measure of how detectable the vital signs are. In radar applications, the Radar Cross Section (RCS) is normally used to characterize the detectability of an object. Since the human vital signs are seen by the radar as movements of the torso, the modulations in the person RCS can be used as a system independent measure of the vital signs detectability.

In this paper, measurements of persons seated in an anecoic chamber are presented. The measurements were calibrated using empty room and a metallic calibration sphere. A narrowband radar operating at frequencies from 500 MHz to 18 GHz in discrete steps was used. A turntable provided measurements at precise aspect angles all around the person under test.

In an I & Q receiver, the heartbeat and respiration modulation is a combination of amplitude and phase modulations. The measurements were filtered, leaving the modulations from the vital signs in the radar recordings. The procedure for RCS computation was applied to these filtered data, capturing the complex signatures. It was found that both the heartbeat and respiration detectability increase with increasing frequency. The heartbeat signatures are almost equal from the front and the back, while being almost undetectable from the sides of the person. The respiration signatures are slightly higher from the front than from the back, and smaller from the sides.

The signature measurements presented in this paper provide an objective system independent measure of the detectability of human vital signs as a function of frequency and aspect angle. These measures are useful for example in system design and in assessing real measurement scenarios.

9461-13, Session 11

The Born approximation, multiple scattering, and algorithm

Alejandro F. Martinez, Zhijun G. Qiao, The Univ. of Texas-Pan American (United States)

Radar works by focusing a beam of light and seeing how long it takes to reflect. To see a large region the beam is pointed in different directions. The focus of the beam depends on the size of the antenna (called an aperture). Synthetic aperture radar (SAR) works by moving the antenna through some region of space. A fundamental assumption in SAR is that waves only bounce once. Several imaging algorithms have been designed using that assumption. The scattering process can be described by iterations of a badly behaving integral. Recently a method for efficiently evaluating these types of integrals has been developed. We will give a detailed implementation of this algorithm and apply it to study the multiple scattering effects in SAR using target estimates from single scattering algorithms.

9461-46, Session 11

Micro-Doppler characteristics of elderly gait patterns with walking aids

Moeness G. Amin, Yimin D. Zhang, Fauzia Ahmad, Villanova Univ. (United States)

Radar is an effective sensing modality for providing self-dependent living

to the elderly due to its non-intrusive nature and the ability to preserve privacy, detect human motions in all types of environments, and insensitivity to lighting conditions. However, analysis of the radar returns associated with human motions can be a demanding task, given their complex nature that stems from the presence of multiple signal components which correspond to various parts of the moving body. In this paper, we analyze the micro-Doppler characteristics of narrowband radar signals corresponding to elderly gait. More specifically, we consider gait patterns both with and without walking aids, such as walking canes and walkers. Using real data, we demonstrate the differences in the radar signatures of elderly walking with and without aids.

9461-47, Session 11

Fall detection and classification using high-resolution time-frequency distributions

Moeness G. Amin, Villanova Univ. (United States); Boualem Boashash, Qatar Univ. (Qatar); Yimin D. Zhang, Villanova Univ. (United States)

Radar Micro-Doppler is the phenomenon of the observed micro-motions on top of the bulk main Doppler component of a target's motion. It has been the subject of research over a number of years focusing on the additional information that can be extracted from this signal. Such information can then be exploited in a variety of applications for security, law enforcement, urban warfare, and search and rescue, where the detection, tracking, and classification of many human targets moving in a cluttered environment is of paramount importance. These signals are also associated with radar returns from vibrating, oscillating, and rotating targets.

Motion classifications based on target micro-Doppler signatures are typically based on time-frequency analyses of the radar returns. Spectrograms have been the de facto joint-variable signal representation, depicting the signal power in both time and frequency. Several papers on motion classifications using radar proceed to extract pertinent features to the motion profiles of interest in the time-frequency domain and then apply these features to a classifier. Although there have been major advances in designing quadratic time-frequency distributions (TFDs) which are superior to spectrograms in terms of detailing the local signal behavior, the contributions of these distributions in the area of human motion classifications and their offerings in enhanced feature extractions have not yet been properly evaluated.

In this paper, we examine the role of high resolution time-frequency distributions for fall detection. The work supports the recent and rising broad interest in using emerging radar technology for elderly care and assisted living. The paper contributions are twofold and as follows: 1. We show the effect of using high resolution TFDs, in lieu of spectrograms on classification rates of the fall. We use features which have been commonly identified and used in association of falls and spectrograms; 2. We devise new features in congruence with high resolution TFDs which exploit the level of details provided by these distributions in comparison with the coarse and smoothed time-frequency signatures offered by spectrograms.

Conference 9461B: Active and Passive Signatures VI

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9461-56, Session 12

Human activity classification using time-frequency image analysis of micro-Doppler signatures

Matthew Zenaldin, Ram M. Narayanan, The Pennsylvania State Univ. (United States)

We investigate the viability of classifying human activities by utilizing the micro-Doppler effect in radar. To this end, measured data on 5 human subjects performing various activities were collected using a continuous-wave X-band Doppler radar. Some activities included walking, running, arm swinging, crawling, and crouching-to-standing. The time-frequency distribution signatures resulting from these movements were then analyzed as images, thereby inviting image classification techniques to the field of non-stationary signal analysis. Analysis showed that it was possible to classify human movements based upon their time-frequency signatures. We report on the results of our classification approach.

9461-57, Session 12

Study of the micro-Doppler signature of a bicyclist for different directions of approach

Berta Rodriguez-Hervas, The Univ. of Texas at El Paso (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)

Autonomous driving in urban environment critically depends on the ability of its environment perception system to detect and to correctly classify vulnerable road users such as pedestrians and bicyclists in dense, complex environments. Self-driving vehicles include sensing systems such as, cameras and radars to enable the vehicle in decision-making situations. Among the sensor systems, radars are particularly relevant, due to their operational robustness under adverse weather or illumination conditions and their large field of view. Classification of pedestrians and car targets in the same environment with automotive radar has been widely investigated, proving the microdoppler signature to be the most suitable feature for target discrimination. Our objective is to analyze and study the micro-Doppler signature of bicyclists approaching the vehicle hosting the radar system from different directions in order to establish the basis of a classification criterion to distinguish bicycles from other target types.

The micro-Doppler signature of the targets (i.e. cars, pedestrians, bicyclists, clutter) is established by grouping individual reflecting points in objects by the use of a clustering algorithm, observing the evolution of all the points belonging to an object in the Doppler domain over time, and establishing the relation with the kinematic model of bicyclists' movement. We will discuss the suitability of the microdoppler signature of bicyclist targets as a classification feature by comparing their microdoppler spectrum with those belonging to cars and pedestrians approaching the radar systems with similar direction and velocity characteristics.

9461-58, Session 12

Extracting and analyzing micro-Doppler from ladar signatures

David Tahmoush, U.S. Army Research Lab. (United States)

Ladar and other 3D imaging modalities have the capability of creating 3D micro-Doppler to analyze the micro-motions of human subjects. An additional capability to the recognition of micro-motion is the recognition of the moving part, such as the hand or arm. Combined with measured RCS values of the body, ladar imaging can be used to ground-truth the more sensitive radar micro-Doppler measurements and associate the moving part of the subject with the measured Doppler and RCS from the radar system. The 3D ladar signatures can also be used to classify activities and actions on their own, achieving an 86% accuracy using a micro-Doppler based classification strategy.

9461-59, Session 12

High range resolution micro-Doppler analysis

Graeme E. Smith, The Ohio State Univ. (United States); Zach Cammenga, The Ohio State University (United States); Christopher J. Baker, The Ohio State Univ. (United States)

The micro-Doppler (μD) effect and high range-resolution (HRR) profiles have both capable of providing target signatures that are unique and can form the basis of radar automatic target classification or recognition systems. However, μD is usually considered in CW or sampled CW situations that are not conducive to obtaining HRR profiles and, as such, most analysis of the techniques are independent. Here, the signatures are considered together with the aim of providing a joint μD-HRR target characterization that will provide greater target information for classification.

This research focuses on how to analyze μD-HRR signatures. Chen and Smith have previously considered such analysis; their technique focused on forming a joint range-time-frequency data cube. However, neither of the analyses they provide explores the technique in depth, and they focus instead on their data. Here real and simulated data of a walking person target illuminated with a W-band radar will be used explore the range-time-frequency data cube and understand what additional target information can be obtained from it.

The range cuts through the data cube provide a target signature in which the μD signature is naturally separated components. The data cube can then be reprocessed into 2D image that counts of the number of scattering centres comprising the target at each range, as a function of slow time. This analysis has the potential extract the target micro-motions without requiring assumptions about the number of scattering centres and their motion models—a common limitation of micro-motion extraction methods.

9461-60, Session 13

Application of a laser Doppler vibrometer for air-water to subsurface signature detection

Phillip Land, James Roeder, Dennis J. Robinson, Arun K. Majumdar, Naval Air Warfare Ctr. Weapons Div. (United States)

There is much interest in detecting a target and optical communications from an airborne platform to a platform submerged under water. Accurate detection and communications between underwater and aerial platforms would increase the capabilities of surface, subsurface, and air, manned and unmanned vehicles engaged in oversea and undersea activities. The technique introduced in this paper involves a Laser Doppler Vibrometer (LDV) for acousto-optic sensing for detecting acoustic information propagated towards the water surface from a submerged platform inside a 12 gallon water tank. The LDV probes and penetrates the water surface

from an aerial platform to detect air-water surface interface vibrations caused by an amplifier to a speaker generating a signal generated from underneath the water surface (varied water depth from 1" to 8"), ranging between 50Hz to 5kHz. As a comparison tool, a hydrophone was used simultaneously inside the water tank for recording the acoustic signature of the signal generated between 50Hz to 5kHz. For a signal generated by a submerged platform, the LDV can detect the signal. The LDV detects the signal via surface perturbations caused by the impinging acoustic pressure field; proving a technique of transmitting/sending information/messages from a submerged platform acoustically to the surface of the water and optically receiving the information/message using the LDV, via the Doppler Effect, allowing the LDV to become a high sensitivity optical-acoustic device. The technique developed has much potential usage in commercial oceanography applications. The present work is focused on the reception of acoustic information from an object located underwater.

9461-61, Session 13

Hyperspectral chemical agent standoff detection using sparse representation

Asif Mehmood, Booz Allen Hamilton Inc. (United States)

Standoff detection, identification and quantification of chemical agents are fundamental needs in various fields of applications. We propose a sparsity-based algorithm for standoff detection of chemical agents in conjunction with constrained energy minimization (CEM) band selection in Hyperspectral imagery (HSI). The proposed sparsity-based detection (SD) approach relies on the observation that spectral signatures belonging to the same class approximately lie in a low-dimensional subspace. An unknown test sample can be represented by only a few training samples in the structured dictionary, and the underlying sparse representation vector contains discriminative information for detection. The proposed algorithm is applicable to both spectrally pure as well as mixed pixels. Experimental results show that SD outperforms the classical detection algorithms such as generalized likelihood ratio test (GLRT), adaptive coherence estimation algorithms (ACE), and orthogonal subspace projection (OSP).

9461-62, Session 13

Signature simulation of mixed materials

Tyler Carson, Carl Salvaggio, Rochester Institute of Technology (United States)

Soil target signatures vary due to geometry, chemical composition and scene radiometry. Although radiative transfer models and function-fit physical models may describe certain targets in limited depth, the ability to incorporate all three signature variables is difficult. This work describes a method to simulate the transient signatures of soil by first considering scene geometry synthetically created using 3-d physics engines. Through the assignment of spectral data from the Nonconventional Exploitation Factors Data System (NEFDS), the synthetic scene is represented as a chemical mixture of particles. Finally, first principles radiometry is modeled using the Digital Imaging and Remote Sensing Image Generation (DIRSIG) model. With DIRSIG, radiometric and sensing conditions were systematically manipulated to produce and record goniometric signatures. The implementation of this virtual goniometer allows users to examine how a target bidirectional reflectance function (BRDF) will change with geometry, composition and illumination direction. By using 3-d computer graphics models, this process does not require geometric assumptions that are native to many radiative transfer models. It delivers a discrete method to circumnavigate the significant cost of time and treasure associated with hardware based goniometric data collections.

9461-63, Session 13

Enabling forest structure research with a cost-effective terrestrial LiDAR platform

Jason W. Faulring, Jan A. N. van Aardt, David Kelbe, Paul Romanczyk, Rochester Institute of Technology (United States); Francesco Peri, Crystal Schaff, Univ. of Massachusetts Boston (United States)

Light detection and ranging (LiDAR) instruments have become a commonplace tool for the acquisition of spatial point cloud data representative of scenes found in the physical world. Commercially available terrestrial LiDAR systems are capable of generating impressively dense data sets over large distances and often find use in the field of site surveying where this level of performance is demanded. Unfortunately, these units can be bulky, slow and inaccessible for use by many researchers due to the cost of the instrument. Some LiDAR research applications, such as the study of localized forest scenes, can tolerate a lesser overall system resolution and range performance in trade for the ability to have access to a compact, fast and cost-effective sensor that will generate data that is still desirable and valid for the application.

A compact, terrestrial LiDAR platform has been developed that specifically targets the needs of researchers performing field surveys in remote forested areas. The system was designed to minimize the cost, weight and size of the instrument while meeting the resolution and range requirements needed by forest researchers to accurately reconstruct the targeted scene. As computing technology has evolved and hardware has shrunk to support greater capability from system on a chip (SOC) devices, the platform has undergone several generations of mechanical packaging. This has produced an instrument that is easy to field, minimizes the workload of the operator and generates accurate scene data. Presented in this paper is the developed system architecture and the characteristics of the response, accuracy and density of the collected data. Each generation of the platform has been utilized to collect field data at various locations; sample data sets will be presented along with representative post processing work to utilize the data for specific applications.

9461-64, Session 13

Electro-optical detection probability of optical devices determined by bidirectional laser retro-reflection cross section

Martin Laurenzis, Frank Christnacher, Alexis Matwyschuk, Emmanuel Bacher, Stephane Schertzer, Sebastien Hengy, Institut Franco-Allemand de Recherches de Saint-Louis (France)

The menace of sniper attacks became more and more serious for own troops in hostile urban environments as in MOUT (Military Operation in Urban Terrain) scenarios. Measures to detect snipers were widely discussed in the defense community. At the French-German Research Institute of Saint-Louis (ISL), the acoustical and electro-optical means to detect and locate snipers before and during the attack was investigated in the frame of an interdisciplinary project, called IMOTEP (IMprovement Of optical and acoustical TEchnologies for the Protection). Here, the use of a distributed sensor network was studied including transmission and fusion of heterogeneous sensor information.

In the present publication, the authors want to focus on the electro-optical detection of retro-reflections, only. A good measure for the possibility to detect a sniper's telescopic sight is the effective laser cross section and the orientation of the optics or its bidirectional retro-reflection cross section. This spectral and angular (bi-directional) property of an optical device can be measured and, thus, gives a fist reliable value to estimate its probability to be detected by a given active imaging system. At ISL, a systematic study of different optics as well as false targets was performed. As a result, a

model for DRI range predictions depending on situational parameter is presented. Further, a new method to evaluate active signatures is presented which effectively reduce false alarm rates by classification of retro-reflector types in a principal component analysis matrix.

9461-65, Session 13

Spectral reflectance variability of skin and attributing factors

Catherine C. Cooksey, Benjamin K. Tsai, David W. Allen, National Institute of Standards and Technology (United States)

Knowledge of the spectral reflectance signature of human skin over a wide spectral range will help advance the development of sensing systems for many applications, ranging from medical treatment to security technology. A critical component of the signature of human skin is the variability across the population. We describe a simple measurement method to measure human skin reflectance of the inside of the forearm. The variability of the reflectance spectra for a number of subjects measured at NIST is determined using statistical methods. The degree of variability is explored and an attempt to explain the variability is made based on known physiological models. We also propose a method for collaborating with other scientists, outside of NIST, to expand the data set of signatures to include a more diverse population and perform a meta-analysis to further investigate the variability of human skin reflectance.

9461-66, Session 13

Rugged target standards for HSI remote sensing

Mark Morey, John D. DiBenedetto, Mary O'Neill, National Security Technologies, LLC (United States)

There is a need for stable test standards for many remote sensing applications that can be used both in the laboratory and in rugged test environments. Ideally these standards would be stable over time such that the same standard could be used from year to year for comparison of system performance. While ink-jet and spray gun methods can disperse controlled doses of dissolved analytes, methods to maintain particle size spectral variations are lacking. In addition, standards that are environmentally robust and stable over time are limited. As part of the recent Lighthouse work toward a Hyperspectral Imagery (HSI) proximal handheld sensor, Special Technologies Laboratory (STL) was tasked to do preliminary work toward a rugged, transportable, waterproof target board. This involved developing test standards using minerals of known particle sizes that have spectrally relevant features. Mineral powders were dispersed in binders that did not change their spectral characteristics. These standards were packaged such that they could be transported and used repeatedly. This paper discusses the methodology for developing this preliminary set of targets. Target sizes were limited to the proximal case, and further work is required to finalize the optimum binder and examine other possible appropriate minerals.

9461-67, Session 13

Enhancing radar cross-section images of artificial targets using radar polarimetry

Thomas Dallmann, Dirk Heberling, RWTH Aachen Univ. (Germany)

Nowadays polarimetric decompositions are common processing techniques for synthetic aperture radar images. However, some of the decomposition methods can also be applied to imagery obtained in radar cross-section (RCS) measurement ranges. Since commonly artificial targets are measured in these ranges, coherent decompositions are of special interest for the analysis of these images. In this paper, a known decomposition is used to remove non-polarized clutter from fully polarized targets. Also a variation of this decomposition will be introduced and compared to a well-known image processing lter. Finally it will be demonstrated that both methods can enhance the contrast of RCS images.

9461-68, Session 13

Anomalous reflection of THz pulse containing a few cycles from absorbing layer: influence of absolute phase of the pulse on the medium response

Vyacheslav A. Trofimov, Mikhail V. Fedotova, Elena S. Komarova, Lomonosov Moscow State Univ. (Russian Federation)

We analyze an interaction of THz pulse containing a few cycles with absorbing or transparent layer. This analysis is very important for problem of the detection and identification of substance.

We found out the nonmonotonic dependence of a reflection coefficient from both absorption coefficient, and layer thickness, and absolute phase of the pulse. Absorption energy depends on these characteristics also.

Under the interaction of THz pulse with layer of substance the pulse spectrum can essentially change in dependence of layer thickness. As a consequence, excitations of different energy levels occur despite unchanging the spectrum of incident pulse. Therefore, the medium response can change. For problem of the detection and identification this leads to additional requirements with respect to the spectrum of incident THz pulse.

For absorbing layer we see a dependence of absorption energy from the layer thickness. This dependence has maximum with changing of the absorption coefficient because a reflection of laser energy is a function of both dielectric permittivity of medium and its absorption coefficient.

Amplitude of reflected THz pulse depends in strong way from absolute phase of incident THz pulse if the pulse duration is sufficient small.

9461-69, Session 14

Applying composite signatures to rapidly detect and characterize

Chadwick T. Hawley, U.S. Dept. of Defense (United States) and Help Me Now, LLC (United States)

A composite signature is a group of signatures that are related in such a way to more completely or further define a target or operational endeavor at a higher fidelity. This paper explores new applications using composite signatures, in lieu of waiting for opportunities for the more elusive diagnostic signatures to satisfy key essential elements of information (EEI) associated with civil disaster-related problems. It discusses efforts to refine composite signature development methodology and quantify the relative value of composite vs. diagnostic signatures. The objectives are to: 1) investigate and develop innovative composite signatures associated with civil disasters, including physical, chemical and pattern/behavioral; 2) explore the feasibility of collecting representative composite signatures using current and emerging intelligence, surveillance, and reconnaissance (ISR) collection architectures leveraging civilian and commercial architectures; and 3) collaborate extensively with scientists and engineers from U.S. government organizations and laboratories, the defense industry, and academic institutions.

9461-70, Session 14

Real-time full-motion color Flash-LIDAR for target detection and identification

Roy D. Nelson, Eric Coppock, Rex M. Craig, Jeremy Craner, Dennis Nicks, Kurt von Niederhausern, Ball Aerospace & Technologies Corp. (United States)

Real-time, full motion Flash- LIDAR, when combined with multi-spectral context imagery and inertial navigation data, provides additional modalities for improved understanding of areas or objects of interest and produces truly georegistered 3D imagery. Georegistered 3D full motion video provides crucial information beyond the widely used typical 2D full-motion video (FMV), allowing users to exploit the z dimensional for intelligence. When LIDAR is fused or combined with context imagery, the typical point cloud now becomes a 3D scene which is intuitively obvious to the user and allows rapid cognitive analysis with little or no training. Ball Aerospace has developed a real-time, full motion LIDAR system that fuses context imagery, VIS to MWIR demonstrated, which is capable of streaming fully fused 3D imagery to the user from an airborne platform. LIDAR can now be seen as Laser Imagery, Detection and Ranging. In addition, since the context camera is boresighted and frame synchronized to the LIDAR camera and the LIDAR camera is an array sensor, the context camera higher resolution can be used to apply its pixel RGB values for example to interpolated LIDAR pixel values creating a point cloud that has the same resolution as the context camera, effectively creating an high definition (HD) LIDAR image. This high resolution 3D image provides additional information to the user for improved image analysis or comprehension. This paper presents a design overview of the Ball TotalSight LIDAR system along with typical results over urban and rural areas collected from both rotary and fixed wing aircraft. We conclude with a discussion of future work.

9461-72, Session 14

HySpecIQ: realizing the potential of hyperspectral remote sensing informatics in the age of data analytics

Joseph D. Fargnoli, HySpecIQ (United States)

The potential of Hyperspectral Imaging (HSI) as a transformative information source has been well established through analysis as well as ground, air and space validation. In many cases HSI is a powerful tool but it's full impact has often been under realized because of the absence of a framework for the integration of the degree of information value present even if not complete. HySpecIQ is a global remote sensing informatics business developing a constellation of hyperspectral imaging satellites to be launched from 2018. The HySpecIQ system has two parts, namely: (i) satellite sensors with superior spatial, spectral and radiometric resolutions as well as high temporal frequency/coverage, combined with (ii) "multi-modal interpretation" (MMI) processing capabilities that ingest these satellite data (as well as other spatial information) to generate highly specific (and accurate) information products. In order to overcome some of the historical limitations of HSI and to fully realize the market potential of this data we will introduce a framework whereby HSI MMI is enabled through the use of Upstream Data Fusion (UDF) in order to enable the means and tools for higher levels impact through the application of the principles of Context Accumulation and Relevance Detection. This paper will explain the theoretical underpinnings of this approach as well as provide examples of it's efficacy and validation of it use as building blocks for the realization of the true potency of HSI in practical applications in key Commercial and Government market applications.

9461-73, Session 14

QUILT: combining stereoscopy with lidar for precision 3D object characterization

G. Charmaine Gilbreath, Carlos Omar Font, David Bonanno, Blerta Bajramaj, Kristen Nock, U.S. Naval Research Lab. (United States)

In this paper, we present preliminary experimental results combining active (LIDAR) with passive (stereoscopy) methods to obtain precise voxel-like reference objects as a basis for metrology. These multi-modal signatures promise to provide calibration bases for photogrammetry, computer vision, and other applications. Initial results use a 1550 nm LIDAR with frames from two cameras from two "LadyBug" camera suites.

9461-78, Session 14

High-range resolution micro-Doppler analysis

Zach Cammenga, Graeme E Smith, Christopher J. Baker, The Ohio State Univ. (United States)

The micro-Doppler (?D) effect and high range-resolution (HRR) profiles have both capable of providing target signatures that are unique and can form the basis of radar automatic target classification or recognition systems [1] Chap. 14, [2]. However, ?D is usually considered in CW or sampled CW situations [2] that are not conducive to obtaining HRR profiles and, as such, most analysis of the techniques are independent. Here, the signatures are considered together with the aim of providing a joint ?D-HRR target characterization that will provide greater target information for classification.

This research focuses on how to analyze ?D-HRR signatures. Chen [3] and Smith [4] have previously considered such analysis; their technique focused on forming a joint range-time-frequency data cube. However, neither of the analyses they provide explores the technique in depth, and they focus instead on their data. Here simulated data (and real data in the final paper) will be used explore the range-time-frequency data cube and understand what additional target information can be obtained from it.

9461-79, Session 14

The Johns Hopkins University multimodal human actions dataset

Thomas S. Murray, Daniel R, Mendat, Kayode A. Sanni, Andreas G. Andreou, Johns Hopkins Univ. (United States)

We present the Johns Hopkins University Multimodal Action (JHUMMA) dataset, which contains a set of twenty-one actions. The data was collected with a novel data acquisition system that includes three independent active sonar sensors and RGB-Depth video from a Microsoft Kinect sensor. The data converters on the sensor boards are synchronized using a wireless beacon. We develop a feed-forward physics model for predicting the acoustic micro-Doppler modulations from body tracking data derived from the Kinect sensor. The time-frequency modulations produced by the physics model are compared to the actual active acoustics in the JHUMMA dataset.

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9462-2, Session 1

Optical and imaging performance testing for an improved real time passive millimetre-wave imager to be used in degraded visual environments

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This paper discusses the optical testing and imaging performance of the improved passive mm-wave imager design for use in degraded visual environments for base security and helicopter navigation reported in the 2014 conference.

The testing regime starts with optical component testing, to show whether each optical component conforms to its specification, and predict what effect each component will have on system performance. The testing described includes metrology of surface profiles, measurements of loss for each component, measurements of point spread functions and encircled energy of each component with optical power, and measurements of polarising efficiency on the polarising material and quarter–wave plate used in the system. The performance of the receivers is also measured in terms of noise equivalent temperature difference, frequency response and receiver feed horn beam pattern. Also described is the design of two corrector test lenses which allow either imager component with optical power to form a sharp image without the presence of the other component, and thus be tested individually.

Testing of the full optics is described, both using a single scanned receiver and later the full receiver array. The former gives better sampled point spread functions; the latter better represents the full system. The loss, effective aperture, field of view, depth of field, narcissus, thermal and fixed-pattern noise are also measured. Iterative methods to set the tolerance compensation and optimise the scan conversion look up tables are described.

Finally testing of the system imaging performance on bar targets and simple scenes is described.

9462-3, Session 1

Design and operation of ACTPol: a millimeter wavelength, polarization sensitive receiver for the Atacama Cosmology Telescope

Benjamin L. Schmitt, Univ. of Pennsylvania (United States); ACTPol Collaboration, Princeton Univ. (United States)

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, and second season operations completed in late-2014, 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 will be highlighted as an example of a standoff security system that has successfully leveraged integrated technologies originally developed for millimeter-wavelength cosmology applications, within systems such as ACTPol.

9462-4, Session 1

Concealed object stand-off real-time imaging for security: CONSORTIS

Roger Appleby, InnovaSec Ltd. (United Kingdom); Stuart Ferguson, Queen's Univ. Belfast (United Kingdom); Henrik Petersson, Swedish Defence Research Agency (Sweden)

Within the European commission Seventh Framework Programme (FP7), CONSORTIS will design and fabricate a stand-off system for the detection of objects concealed on people operating at sub-millimetre wave frequencies. This system will scan people as they walk by the sensor. The aim of the project is to produce a system which has a high probability of detection, low false alarm rates, is non-invasive and respects privacy.

This paper presents the top level system design which brings together both passive and active sensors and discusses the trade-offs required to deliver the necessary performance. The passive system will operate in two bands between 100 and 600GHz and will be based on a cryogen free cooled focal plane array sensor whilst the active system will be a solid-state 340GHz radar. This will maximize the probability of detection and reduce false alarms. A 'systems engineering' approach is adopted with performance modelling being used to develop the system specifications. The results of this modelling and how they impact on the design will be discussed. A modified version of OpenFx is used for the passive system and SE-RAY-EM for the active system. Both of these tools are capable of rendering imagery which is electromagnetically correct and accounts for the properties of the sensor. Furthermore this imagery can be animated as in the real system. Targets can be embedded under clothing so that performance can be estimated. False alarms can be introduced in a similar way to understand if their signatures can be rejected. The strengths and weaknesses of this approach will also be discussed.

9462-5, Session 1

Toward a real time stand-off submillimeter-wave imaging system with large field of view: quasi-optical system design considerations

Erio Gandini, Nuria Llombart, Technische Univ. Delft (Netherlands)

We are developing, in the frame-work of the European project CONSORTIS, a stand-off system for concealed object detections working at submillimetre-wave frequencies. The system is required to perform real time image acquisition over a large field of view using both an active and passive sensor. Here we present the quasi-optical system design that operates in the frequency range from 250 to 500 GHz with a field of view that is approximately the size of a human body, 1x2 m2. The quasi-optical system acquires images from 2m to 5m range with 1 cm spatial resolution. Focal plane arrays are used to achieve high imaging frame rates. Two configurations are analyzed: a sparse array with 1x8 active transceivers and a 10000 element incoherent passive staring array. Both cases use mechanical scanning to achieve the required field of view.

This paper presents an in-depth analysis of the different trade-offs driving the quasi-optical design: from the achieved imaging speed to the optical beam quality over the whole field of view. This analysis starts from the fundamental limitations of the quasi-optical systems and mechanical scanners. The required motor performance to achieve real time imaging is discussed as a function of the sampling patterns. The performance of the commercial motors are then linked to the quasi-optical system design.

After understanding the fundamental trade-offs, we present two practical implementations that fulfil the requirements for both types of imaging array configurations. The simulated performance in terms of beam quality, sensitivity and expected imaging speeds will be presented.

9462-6, Session 1

Noise analysis for near-field 3D FM-CW radar imaging systems

David M. Sheen, Pacific Northwest National Lab. (United States)

Near field radar imaging systems are used for several applications including concealed weapon detection in airports and other high-security venues. Despite the near-field operation, phase noise and thermal noise can limit performance in several ways. Practical imaging systems can employ arrays with low gain antennas and relatively large signal distribution networks that have substantial losses that limit the transmitted power and increase the effective noise figure of the receiver chain, resulting in substantial thermal noise. Phase noise can also limit system performance. The signal coupled from transmitter to receiver is much larger than expected target signals. Phase noise from this coupled signal can set the system noise floor if the oscillator is too noisy. Frequency modulated continuous wave (FM-CW) radar transceivers used in short range systems are somewhat immune to the effects of the coupled phase noise due to range correlation effects. This effect can push the phase-noise floor below the thermal noise floor for moderate performance oscillators. Phase noise is also manifest in the range response around bright targets, and can cause smaller targets to be obscured. Noise in synthetic aperture imaging systems is mitigated by the processing gain of the system. In this paper, the effects of thermal noise, phase noise, and processing gain are analyzed in the context of a near field 3-D FM-CW imaging radar as might be used for concealed weapon detection. In addition to traditional frequency domain analysis, a time-domain simulation is employed to graphically demonstrate the effect of these noise sources on a fast-chirping FM-CW system.

9462-7, Session 2

Millimeter-wave imaging at up to 40 frames per second using an optoelectronic photo-injected Fresnel zone plate lens antenna at (sub-) mmw frequencies

Thomas F. Gallacher, Aalto Univ. School of Science and Technology (Finland); David G. Macfarlane, 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 a promising pathway for realizing rapid and highly reconfigurable beam steering for a wide range of applications, ranging from microwave through to terahertz frequencies. In particular, the photo-injected Fresnel zone plate antenna (piFZPA) method, wherein a dynamic binary lens antenna is created by the opto-excitation of a Fresnel zone plate plasma within a suitable semiconductor substrate, 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 and discuss the latest results obtained using a novel piFZPA architecture. The key system design leverages the advantages of an integrated OEM digital light projection (DLP) spatial light modulator for rapid mask reconfiguration. A range of experimental results will be presented and discussed that include a range of designs which demonstrate up to 17,500 beams per sec, and which readily yield up to 40 (mmw) frames per sec when configured to generate 1D plan-polar-images (PPI). Other imaging modalities will also be discussed demonstrating up to 7 frames per second with moderate density 2D FOVs. The latest measurements demonstrate a wide field-of-view and highlight a 3-order-of-magnitude increase in beam rates to those presented previously, whilst also extending the operating frequency beyond 100 GHz.

9462-8, Session 2

Characteristics and performance of a commercial multiband passive submillimetre-wave video camera

Arttu R. Luukanen, Asqella Oy (Finland); Juha Ala-Laurinaho, Aalto Univ. School of Electrical Engineering (Finland); Alex Kokka, Mikko M. Leivo, Asqella Oy (Finland); Aleksi A. Tamminen, Aalto Univ. School of Electrical Engineering (Finland); Antti V. Räisänen, Aalto Univ. School of Science and Technology (Finland)

The paper summarizes the imaging performance of Asqella's new passive multi-band THz imaging system - the Argon. The camera operates at three wavebands between 250 GHz and ~620 GHz, at a frame rate of ~10 fps, capturing a ~2 m diameter field-of-view at a 5 m fixed imaging distance. The measured performance of the system will be presented with some of its unique features.

9462-9, Session 2

Video rate passive millimeter-wave imager utilizing optical upconversion with improved size, weight, and power

Richard D. Martin, Christopher A. Schuetz, Thomas E. Dillon, Daniel G. Mackrides, Phase Sensitive Innovations, Inc. (United States); Dennis W. Prather, Shouyuan Shi, Univ. of Delaware (United States); Peng Yao, Phase Sensitive

Innovations, Inc. (United States); Kevin Shreve, Univ. of Delaware (United States)

In this presentation we will discuss performance and limitations of our 220 channel video rate passive millimeter wave imaging system based on a distribute aperture with optical upconversion architecture. We will cover our efforts to reduce the cost, size, weight, and power (CSWaP) requirements of our next generation imager. To this end, we have developed custom integrate custom silicon-germanium (SiGe) low noise amplifiers that have been designed to efficiently couple with our high performance lithium niobate upconversion modules. We have also developed millimeter wave packaging and components in multilayer liquid crystal polymer (LCP) substrates which greatly improve the manufacturability of the upconversion modules. These structures include antennas, substrate integrated waveguides, filters, and substrates for InP and SiGe mmW amplifiers.

9462-10, Session 2

Optical-network-connected multi-channel 96-GHz-band distributed radar system

Atsushi Kanno, Toshiaki Kuri, Tetsuya Kawanishi, National Institute of Information and Communications Technology (Japan)

The millimeter-wave (MMW) imaging technique is being extensively developed for civil security applications. Owing to its short wavelength, it can achieve high resolution and its penetrability allows the detection of hidden weapons in clothing. However, its high atmospheric attenuation coefficient limits its detection range and, thus, large-area surveillance requires a large number of radar heads. An optical fiber network is the optimal solution to transport such high-bandwidth signals to remote sites owing to its low loss of 0.2 dB/km. Therefore, an optical-fiber-connected MMW imaging system with a large number of heads in the distributed antenna system (DAS) configuration can perform high-resolution surveillance of large areas, such as airport runways and railways. An optical-fiber-connected radar system has already been reported and demonstrated in the 96-GHz band, which is allowed for radiolocation in the US, the EU, and Japan. In recent years, fiber-connected radar system has been developed in 90-GHz band using analog-based radio-over-fiber technologies. Frequency-modulated continuous-wave (FM-CW) signal by an optical multiplication based on optical modulation techniques can provide broad-bandwidth signal with identical degradation of phase noise by multiplication. For realization of the large-area surveillance, multi-channel radar system connected by an optical fiber network should be configured.

This paper reports on a wavelength-division-multiplexed (WDM) multi-channel optical signal generation for a frequency-modulated continuous-wave radar signal at 96 GHz, its distribution, and multi-channel radar operation. A four-channel WDM optical FM-CW signal was generated by a high-precision optical modulation technique. These WDM channels were de-multiplexed by a channel selector to transport each radio head. A photomixer converted the optical signal to the MMW radar signal for irradiation. In this paper, only the independent operation of each radar head is shown. A synthetic aperture radar system based on the fiber-connected DAS will be realized in the future.

9462-11, Session 3

Some opinion about matrix terahertz imaging system based on Josephson junctions

Alexander Denisov, Jing Hui Qiu, Shengchang Lan, Harbin Institute of Technology (China); Alexander Gudkov, State Scientific Research Institute of Physical Problems (Russian Federation)

Passive millimeter wave imaging is a method of forming images through the passive detection of naturally existing millimeter wave radiation of the neighborhood situation. Main problem consists of obtaining image in real time in such way as in the infrared thermal imagers or an optical one. This can be fulfilled by using simultaneous receiving of the radiation from different parts of a scene. For simultaneous receiving the creation of array with a large number of the receiving channels and the multibeam quasi-optical antenna are required. The passive millimeter-wave imaging systems (PMWIS) were developed from a single-channel scanning imager [1] to the fully staring array, which contains more than thousands of the receivers [2]. PMWIS is new type of the critical technologies, because it is new fields of human activities, so there are big interests to develop the principal new technologies for the construction focal plane matrix with a lot of receiving pixels. 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. Undoubtedly, various current technical realizations which have place in this field of knowledge depend on the concrete principal trends of the scientific world level teams [3] which move forward their principal achievements.

In our opinion best natural “candidate” for sensor in future PMWIS is Josephson junction (JJ) – it has super wide voltage electronic regulation on frequency by basic ratio 2eV= h? [39]. It can be used without outside heterodyne during the job in self-pumping regime [40, 41]. In this case it will be possible to reach main future advantage and first principal peculiarity – possibility to do choice or changing of the receiving frequency – to do many spectral images analysis by simplest voltage regulation.

In this work there are attempts to evaluate some aspects of such JJ’s application for the receiving radiometric matrix.

9462-12, Session 3

Multiplexable sub-mm detector arrays for radiometric imaging

Juha Hassel, Andrey V. Timofeev, Visa Vesterinen, Hannu Sipola, Panu Helistö, Leif Grönberg, VTT Technical Research Ctr. of Finland (Finland); Arttu R. Luukanen, Asqella Oy (Finland)

We present results on detectors and imager hardware aimed for sub-mm radiometric imaging using staring optics. The detectors are based on nanomembrane-integrated kinetic inductance detectors (KIDs). As opposed to the KIDs developed for astronomy, operating with sub-Kelvin cryogenics, our detectors function at elevated base temperatures in the order of 10 K. Operation with compact cryogenics is a benefit in commercial applications. The proposed technology is aimed as an alternative for the state-of-art imagers based on optomechanical scanning. Our detectors are compatible with multiplexing techniques enabling large 2D arrays. The system can be operated near the intrinsic sensitivity level as limited by the detectors themselves, without the scanning penalty, which improvies the radiometric resolution. Also the optics can be considerably simplified. We present detector characterisation results showing that the detectors are competitive in terrestrial imaging applications. We also present a status report on the development of an imager, based on the technology, considering the issues related to the cryogenics, optics, and electronics.

9462-13, Session 4

Toward the development of an image quality tool for the testing of active millimeter-wave imaging systems

Jeffrey Barber, James C. Weatherall, Joseph Greca, Battelle Memorial Institute (United States); Barry T. Smith, U.S. Dept. of Homeland Security (United States)

Government agencies worldwide have deployed active millimeter wave

(MMW) imaging systems for screening personnel. In the context of aviation security, systems are deployed at checkpoints which run at or near 24-hour operation. While OEM systems may have internal calibration and fault check methodologies, it is desirable to have a tool (or tools) that can be used to independently test the operation/performance of the system from developmental testing through daily commissioning at the checkpoint. To this end, the United States Department of Homeland Security (DHS) has initiated an effort to develop an image quality tool capable of testing active MMW imaging systems. As part of this effort, DHS is seeking to engage the millimeter wave community in a dialogue in order to obtain feedback on design concepts.

Potential embodiments of an image quality tool may contain materials that mimic human skin in order to provide a realistic signal return for testing. These materials may also help reduce or eliminate the need for mock passengers for developmental testing. Two candidate materials, a dielectric liquid and an iron-loaded epoxy, have been identified and reflection measurements have been performed using laboratory systems in the range 18 – 40 GHz. Results show good agreement with both laboratory and literature data on human skin. Issues related to the practical use of liquids and magnetic materials for image quality tools will be discussed.

9462-14, Session 4

Simulations and image validation for 350 GHz passive imaging systems

Daniel T. Becker, National Institute of Standards and Technology (United States); Peter A. R. Ade, Cardiff Univ. (United Kingdom); James A. Beall, National Institute of Standards and Technology (United States); Hsiao-Mei Cho, Stanford Univ. (United States); Simon R. Dicker, Univ. of Pennsylvania (United States); William D. Duncan, National Institute of Standards and Technology (United States); Mark Halpern, The Univ. of British Columbia (Canada); Gene C. Hilton, National Institute of Standards and Technology (United States); Kent D. Irwin, Stanford Univ. (United States); Nicholas G. Paulter Jr., Robert E. Schwall, Carl D. Reintsema, National Institute of Standards and Technology (United States); Carole E. Tucker, Cardiff Univ. (United Kingdom)

Over the past few years multiple groups have developed passive imaging systems operating at submillimeter wavelengths. Here at NIST we have built a 350 GHz video imager operating at standoff distances of 16 m using an array of 251 superconducting detectors. To confirm the observations made with our imaging system, we have developed a physically accurate simulation tool for estimating the effects of various scene parameters on our imager's performance. This tool can predict the appearance of a simple scene, given the optical properties and temperatures of the materials in the scene. The simulation provides a real-time demonstration that helps understand the tradeoffs in image quality inherent in different design decisions and can also be used to validate different approaches to image processing and scanning.

9462-15, Session 4

Spectral signatures for identifying explosives with wide-band millimeter-wave illumination

James C. Weatherall, Jeffrey Barber, Battelle Memorial Institute (United States); Barry T. Smith, U.S. Dept. of Homeland Security (United States)

Millimeter wave imaging is employed in Advanced Technology Imaging (AIT) systems to screen personnel for concealed explosives and weapons. AIT systems deployed in airports auto-detect potential threats by highlighting the threat location on a generic passenger shape, with the imaging data collected over a range of frequency. We demonstrate a method for extracting dielectric constant from the free-space, multi-frequency reflection data, using 18 – 40 GHz. The reflection coefficient is a function of frequency because of propagation effects that relate to the material's complex dielectric constant. By numerically fitting the reflection coefficient as a function of frequency to a theoretical model based on geometric optics, a solution can be found for the complex dielectric constant and target thickness.

The measurement of dielectric constant, including dielectric loss, from the reflection data provides signatures useful for threat identification. In this paper, the method is demonstrated with inert substances and a military sheet explosive to show that detected reflection data can discriminate the materials in a two-dimensional dielectric space. In principle, the detection of reflection coefficient using multiple frequencies can be incorporated into Advanced Imaging Technology (AIT) and standoff imaging systems to provide identifying data on the composition of potential threats, which would allow threat assessment to be accomplished within the scope of millimeter wave screening.

9462-16, Session 4

Summary and analysis of 216 GHz polarimetric measurements of in-situ rain

Abigail S. Hedden, David A. Wikner, Russell Bradley, U.S. Army Research Lab. (United States)

Degraded visual environments remain a significant operational challenge. In addition to other hazards, obscurants like clouds and rain limit the operational support capabilities that overhead aircraft can provide to the Warfighter on the ground. Atmospheric penetration properties, the ability to form high-resolution imagery with modest apertures, and available source power make the extremely high-frequency (EHF) portion of the spectrum promising for the development of radio frequency sensors capable of penetrating visual obscurants, including rain and fog. Comprehensive phenomenology studies, including polarization and backscatter properties of relevant targets, are lacking at these frequencies. The Army Research Laboratory has developed a fully-polarimetric frequency-modulated continuous-wave instrumentation radar designed for carrying out EHF phenomenology studies, specifically, around the 220 GHz atmospheric window. This work summarizes measurements of the polarization and backscatter properties of in-situ rain.

9462-17, Session 4

Electromagnetic scattering from metallic and dielectric surfaces at millimeter-wave and terahertz frequencies

David A. DiGiovanni, Andrew J. Gatesman, Robert H. Giles, Univ. of Massachusetts Lowell (United States); Williams E. Nixon, National Ground Intelligence Ctr. (United States)

With the demand for larger bandwidths and faster data speeds, wireless communication systems are expanding into the millimeter-wave and terahertz region of the electromagnetic spectrum. Successful transition to higher frequencies, particularly for systems located in indoor or urban environments, will require a thorough understanding of reflection, transmission, absorption, and scattering of a wide variety of materials. For this study, the co-polarization and crosspolarization backscattering coefficients of several structures were measured in compact radar ranges operating from 100 GHz to 1.55 THz. These structures consisted of metallic plates, dielectric structures, and a variety of common building materials. Simple rough surface scattering theory was compared to the measured backscattering coefficients of the metallic and dielectric structures. The

backscattering measurements of these materials were compared as a function of polarization, incident angle, and frequency.

9462-18, Session 4

Beyond the Kirchoff approximation: quantitative studies of submillimeter rough surface scattering

Erich N. Grossman, Richard A. Chamberlin, Josh Gordon, Natalie Mujica-Schwahn, National Institute of Standards and Technology (United States)

The Kirchoff-Spizzichino treatment of rough surface scattering is, to date, the most sophisticated scattering theory to have been applied at submillimeter wavelengths. However, the low curvature assumption underlying it precludes any ability to analyze important effects such as enhanced backscatter, that have been well studied in other wavelength regimes. In this study, we have quantitatively compared the predictions of a recent, more general theory developed by A. Fung using the Integral Equation Method (IEM) with predictions based on the Kirchoff-Spizzichino treatment, and with measurements performed over the 160-650 GHz band on a variety of test samples. The samples included both well-controlled, artificially prepared, laboratory surfaces and common, everyday surfaces presented by (for example) common building materials. In all cases, the statistical properties of the surface topography (roughness and autocorrelation function) were carefully analyzed in three dimensions using focus-variation microscopy data. Although the measurements were confined to scattering only in the plane of incidence, we generally find very good agreement between IEM theory and measurement. Except for the very smoothest, most weakly scattering, samples, we find normalized scattering cross-sections (or alternatively bidirectional reflectance distribution functions) within 2 dB of IEM predictions over a wide dynamic range.

9462-19, Session 5

Automatic detection of hidden threats in the TeraSCREEN passive millimeter-wave imaging subsystem

Satish Madhogaria, Marek Schikora, Fraunhofer FKIE (Germany)

Passive millimeter-wave imaging systems have a broad application in security applications. Especially the detection of hidden threats for border security, e.g. on airports, is a growing field. However, the gained images have very small spatial resolution and are therefore hard to analyze fully automatically. In this paper we propose a novel approach for automatic threat detection using a time series of 94 GHz passive millimeter-wave images. Herein, we discuss four principle steps essential to solve the task of threat detection: pre-processing, region-of-interest (ROI) extraction, threat extraction in each frame and finally reaching a conclusion by examining results from all frames. We discuss the problems incurred in each step and propose a solution. For pre-processing, we apply a linear transformation to the intensity values to enhance the contrast. ROI extraction involves human-like contour extraction, convex hull (of the human-like contour) computation and finally extraction of all the points that lies inside the convex hull. This step is essential to get rid of background noise, which is turn reduces considerable amount of false detections. Finally, threat detection is carried by separating appropriate closed contours based on the shape and size. Final decision is taken automatically by fusion of the results from all frames and examining the most concentrated region inside the fused image. Besides showing that the proposed method works very well and reliably for the data set at hand, we also discuss the advantages of using this method in contrast to state-of-the-art methods, i.e. segmentation-based detection [(Martinez, 2010)].

9462-20, Session 5

Feasibility of radon imaging reconstruction in the MMW region using very inexpensive plasma GDD lamps with new video rate 16x16 FPA camera

Assaf Levanon III, Ben-Gurion Univ. of the Negev (Israel); Michael Konstantinovsky II, Ben-Gurion Univ. of the Negev (Israel) and Intel Corp. (United States); Yitzhak Yitzhaky, Adrian Stern, Natan S. Kopeika, Ben-Gurion Univ. of the Negev (Israel); Amir Abramovich, Ariel Univ. (Israel)

A new approach which combines two interesting fields is presented. Compressed imaging (CI), along with Millimeter Wave (MMW) imaging, is suggested in order to implement real time MMW compressed imaging. CI is a joint sensing and compressing process that attempts to exploit the large redundancy in typical images in order to suffice with fewer samples. In general, in Compressing Sensing (CS) there is no need to collect all the signal elements. It is enough to collect much fewer signal components in the transform domain where a large number of the signal frequency components are almost zero or negligible and not included in the data acquisition. This approach, unlike other methods of image acquisition which rest on the Nyquist–Shannon sampling theorem, does not require it. MMW based imaging systems are required for a large variety applications in many growing fields such as medical imaging, homeland security, concealed weapon detection, prevention of smuggling, and space technology. Moreover, the possibility to create reliable imaging in low visibility conditions such as heavy cloud, smoke, fog, and sandstorms in the MMW region, generates high interest. The atmospheric attenuation in this range of the spectrum is relatively low and clear weather scattering is also low compared to the near infrared and visible. The lack of inexpensive room temperature imaging systems makes it difficult to provide a suitable MMW system for many of the above applications. In the last few years we advanced in research and development of imagers using very inexpensive (30-50 cents) Glow Discharge Detector (GDD) plasma indicator lamps as MMW detectors. The GDD is located in free space and it can detect MMW radiation almost isotropically. A system based GDD Focal Plane Arrays (FPA) can be very efficient in real time imaging and yield significant results. The 1st and 2nd FPA generations were an 8?8 pixel array and an 18?2 mono-rail scanner array respectively, both of them for direct detection and limited to fixed imaging. The most recent sensor is a multiplexing frame rate 16x16 GDD FPA. It permits real time video rate imaging of 30 frames per second and comprehensive 3D MMW imaging using chirped heterodyne detection. The principle of detection in this imager is a frequency modulated continuous wave (FMCW) system. However, it also is capable of direct detection while each of the 16 GDD pixels over a line is sampled simultaneously. This FPA is built with 256 commercial GDD lamps of 3 mm diameter and fully supported by Graphical Unit Interface (GUI) software. Here we present a new approach of reconstructing MMW imaging by rotation scanning of the target. The collection process here, based on radon projections, and allows implementation of the compressive sensing principles into the MMW region. This process allows us significant memory saving, working with smaller quantities of detectors, and still being able to process large frames. Feasibility of the concept is demonstrated as radon line imaging. Moreover, new MMW imaging results are presented with our 3rd generation imager for the first time. Combination of these two fields should make significant improvement in MMW region imaging research, and generate new possibilities involving compressing sensing.

9462-21, Session 5

Real-time image processing for passive mmW imagery

Stephen T. Kozacik, Univ. of Delaware (United States) and EM Photonics, Inc. (United States); James Bonnett, Aaron L. Paolini, EM Photonics, Inc. (United States); Thomas E.

Dillon, Richard D. Martin, Christopher A. Schuetz, Phase Sensitive Innovations, Inc. (United States); Dennis W. Prather, Univ. of Delaware (United States)

The transmission characteristics of millimeter waves (mmWs) make them suitable for many applications in defense and security, from airport preflight scanning to penetrating degraded visual environments such as brownout or heavy fog. While the cold sky provides sufficient illumination for these images to be taken passively in outdoor scenarios, this utility comes at a cost; the diffraction limit of the longer wavelengths involved leads to lower resolution imagery compared to the visible or IR regimes, and the low power levels inherent to passive imagery allow the data to be more easily degraded by noise. Recent techniques leveraging optical upconversion have shown significant promise, but are still subject to fundamental limits in resolution and signal to noise ratio.

To address these issues we have applied techniques developed for visible and IR imagery to decrease noise and increase image resolution in mmW imagery. Additionally, we pursued methods for fusing mmW imagery with visible or IR imagery to enhance situational awareness. We subsequently discuss the use of GPU and FPGA platforms for real-time operation of computationally complex image processing algorithms.

We present data from a passive, 77 GHz, distributed aperture, video rate imaging platform captured during field tests at the full video rate. These videos demonstrate the increase in situational awareness that can be gained through applying computational techniques in real-time without needing changes in detection hardware.

9462-22, Session PSThu

Mathematical principles of settings for extremely-high resolution instead of method regularization

Evgeni N. Terentiev, Lomonosov Moscow State Univ. (Russian Federation); Nikolay E Terentiev, HiQo Solutions (Russian Federation)

Mathematical Principles of Settings transforms irregular Apparatus Functions sets to the regular sets invertible and inverse AF's sets. MPS inversion of AFs gives us the non smoothness solutions with the controlled maximum precision and extremely high resolution. Method regularization is based on assumption that the badly conditioned AF remains unchanged. Ill-conditioning or regularization of AF is substituted by the strange object "a priori solution smoothness". As result we have the irreversible and smoothness solutions with the low precision. MPS extremely high resolution and regularization ultra resolution [1] are compared on the old radio-vision image of the Sun in 3 mm wave range.

1. E.N. Terentiev, N.E. Terentiev, "Application of pointed ultra-resolution method in microwave imaging", Proc. SPIE Vol. 5789, 167-177 (2005).

9462-23, Session PSThu

Calibration and image processing method for millimeter-wave holographic imaging

Zheng Li, Tsinghua Univ. (China); Zongjun Shen, Nuctech Co. Ltd. (China); Ziran Zhao, Lingbo Qiao, Tsinghua Univ. (China)

Millimeter-wave imaging technology has wide application prospects in fields of safety inspection due to its low attenuation and non-ionization. It could acquire 3D images with a single scan, which makes it especially suitable for human imaging. In a typical active millimeter-wave imaging system, phase and amplitude information of the target back-projection waves are recorded via an antenna array, which contributes to scanning speed. In our system, the array moves over a rectangular aperture instead of a cylinder one. The antennas variant response characters would lead to non-uniformity artifacts on the reconstructed images, while there are also background scattering waves which have negative effects on the final results. Thus we developed a set of calibration methods to eliminate the influences of system errors including response non-uniformity, transmission delay and background scattering. Assuming antenna response curve linear, calibrations could be achieved via solving response equations. Illuminating targets made of different materials with same signal and recording the response, several response equations are acquired. As the response is a function of input signal, solutions of the equations makes it possible to solve the function expression, with which we can calculate the real back-projection signal to eliminate response non-uniformity. Reconstruction is based on spherical wave decomposition and spatial matched filter. There are certain approximations in the original method. According to Rayleigh-Sommerfeld diffraction formula, we introduce a correction factor related to signal phase and frequency to remove the approximations. Sampling intervals would issue in sub-sampling on the edge of apertures, while there are also Gaussian noises from circuits, which contribute to artifacts over the images. In this case, non-local means filter and its derivate algorithms prove to be efficient according to other researches. In this paper, an improved NL-means algorithm named PRI_NLM3D is introduced. It is a combination of ODCT and RI_NLM3D algorithm, the processing procedure consists of two steps. The method uses hard threshold DCT denoise as pre-filtering and applies original ODCT and NL-means algorithm to the processed image. NL-means utilizes redundancy of images to denoise. The denoised gray value of one pixel is estimated by the weighted average of its neighbor areas. Calculating every pixel in this way, we can get the denoised image. The experimental results prove that the calibration methods contribute to non-uniformity reduction, while non-local means is efficient in eliminating the disturbances of artifacts with little loss of contrast.

Conference 9463: Motion Imagery: Standards, Quality, and Interoperability

Monday - Tuesday 20–21 April 2015

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9463-1, Session 1

Motion Imagery Standards Board (MISB) overview *(Invited Paper)*

Bryan E. Blank, National Geospatial-Intelligence Agency (United States)

This presentation will provide an overview of the Motion Imagery Standards Board (MISB), its activities, recent accomplishments, and focus areas.

9463-2, Session 1

Standards and interoperability 101: standards across the DoD enterprise *(Invited Paper)*

Mark Hary, 2d3 Sensing (United States)

This talk will discuss industry standards used by US government agencies when designing still and motion imagery systems. Both US and NATO STANAGs will be covered. Our investigation will start with low-level sensor standards (covering full motion video, still imagery, and metadata); continue to higher level command and control standards; and then expand to the enterprise and service oriented architectures. We will conclude with looking at cutting edge technology regarding full motion video and still imagery, namely georegistration and 3D reconstruction, and look at the standards will drive adoption of that technology.

9463-3, Session 1

Compression fundamentals: MPEG2, H.264, and HEVC H.265

Karl J. Kuhn, Tektronix, Inc. (United States)

Compression Fundamentals - MPEG2, H.264, and HEVC H.265—The fundamentals of compression will be covered to include the latest H.265/HEVC to maintain high quality at a reduced bitrate. The goal is to provide the highest quality possible at the lowest bitrate required to stay within the design bandwidth limits of the delivery network. Compression is most challenging when tasked with meeting quality requirements on a bandwidth constrained network. Compression is needed to make storage and transport process more efficient. The cost of storage and transport continues to become more affordable but it is not free so compression is a logical process. This presentation will be a tutorial on the practical aspects of maintaining an acceptable Quality of Experience.

This presentation will cover the implementation of Discrete Cosine Transforms and Wavelet JPEG 2000 Compression schemes. Motion estimation and buffer modeling will be discussed as a way to increase efficiency and how the GOP structure can impact system latency. The fundamental differences between MPEG2, H.264, and H.265 will be explained to show how they increase compression efficiency. Screen shots of compression testing tools will be shared to show how they are used to determine the efficiency and stability of a compression algorithm under evaluation.

9463-4, Session 1

FMV end-to-end interoperability

Joseph A. Smith, National Geospatial-Intelligence Agency (United States)

No Abstract Available

9463-6, Session 2

Video test equipment justification process

Karl J. Kuhn, Tektronix, Inc. (United States)

Video Test Equipment Justification Process- Getting the right tools for the job is paramount to being able to run a high quality deployment that all starts with the test equipment justification process and it requires management buy-in to get the budget secured. Staying current with technology is a requirement in today's fast moving world of video to reduce the Unknown Unknowns.

There must be an understanding of the test needs you have today and then being proactive to determine what is needed in the next phases of a project. The test project lead needs to determine what needs to be tested and the risk associates with not testing to make a strong business case to properly fund the test plan. All layers from end to end need to be included in the test plan. All phases of the project need to part of this plan- from early R&D all the way to the everyday operational aspects of a mature deployment. The test project lead needs to always have a ready and current Wish List of required equipment for when funding is incrementally approved.

There is always a cost of not testing but that risk is often not defined as part of the project budget and the project risk assessment. What is the real cost when something goes wrong?This presentation will include several important lessons learned from the presenter's 35 years of testing experience.

9463-21, Session 2

Transitioning from NTSC analog to HD digital Video

Paul Hightower, Instrumentation Technology Systems (United States)

As video systems move from analog NTSC to HD digital video, new system topologies, new transport systems, compression and new data spaces must be considered. This paper will explore some of the tradeoffs and benefits of HD video. There are many new elements of specification that should be considered when designing an HD video system. Throughout, there are tables correlating specifications that define image frames, image sampling and data rates.

This paper will survey HD video and compare the terms between it and analog video. It will also uncover new issues and new capabilities not previously available in analog video systems. For example, SMPTE designed in significant data spaces in each frame that may be used to store time stamps and other time sensitive data. The data space features are a major tool to overcome the issue arising from the introduction of transport latency and image quality impact of compression.

The paper will reveal that resolution is three dimensional in HD where it is defined not only as lines and pixels, but pixel depth. There are a variety of sampling techniques that take advantage of the foibles of our physiology to reduce frame data sizes. Some are barely perceptible to the eye, some compromise image quality to some extent. These sampling techniques

will be described. It will also be shown that regardless of the sampling technique, transport bandwidths of uncompressed HD video must be very wide, or compression must be used to fit the conduit. Similarly, HD video clips can consume enormous data spaces. Only 45 minutes of 1080p/60 uncompressed high profile video requires a terabyte of storage. Once more, compression may be required to collect, edit, distribute and archive HD video sequences. Compression introduces real time latency between the source and destination video. Latencies can be 50 100 milliseconds up to several seconds depending on the complexity of the scene and bandwidth of the transport. Latencies impact human remote control, data collection and time stamping strategies. Latency affects the overlay of time critical measurements; compression threatens the legibility of such overlay when made at the source. Further, other the side effects of compression tools used (e.g. JPEG 2000, MPEG, H.264) to accomplish transport will be discussed.

9463-23, Session 2

WorldView-3 direct geolocation accuracy analysis

Paul C. Bresnahan, Evan H. Brown, National Geospatial-Intelligence Agency (United States)

A geolocation analysis was conducted of WorldView-3 panchromatic imagery. The analysis quantified horizontal and vertical geolocation accuracy by comparing image-derived coordinates to surveyed ground control. Additional analysis included comparisons of observed to predicted errors, geolocation consistency between two imagery product processing levels, and how well the Rational Polynomial Coefficients (RPC) replacement geometry model and the Community Sensor Model (CSM) results match. Through a novel approach the analysis was automated for statistical tabulation, result summaries, and graphing.

9463-8, Session 3

Interfaces, part one: implementation challenges of uncompressed video: 3G-SDI and HDMI with HDCP

Karl J. Kuhn, Tektronix, Inc. (United States)

Part One- Interfaces- Implementation Challenges of Uncompressed Video- 3G-SDI and HDMI with HDCP

ARE YOU LIVING NEAR THE EDGE OF THE DIGITAL CLIFF?

Maintaining quality of HD video and related meta-data and their associated issues are not always apparent in the digital domain. We can no longer just look at the video and listen to audio to determine all its signal quality aspects. Each layer of the underlying digital technology needs to be constantly monitored to see if you are moving closer to the "Digital Cliff".

This presentation will explain how to make sure your content adheres to the "rules of the road" and operates within interoperability requirements. This tutorial will be presented with a focus on the practical aspects you need to know to better understand testing methodology.

The physical layer of HD-SDI and 3G-SDI needs to be clean and stable for the next device in the chain to be able to read the digital signal. The proper use of Eye Patterns and Jitter figure prints will be discussed for troubleshooting source stability issues. CRC and Checksums also need to be regularly monitored to check

the health of active and passive components in the chain. Coax cable best practices will be discussed as well as the move to optical interfaces.

HDMI interfaces with HDCP are now common place in video facilities. Interoperability between Source and Sink is required to allow content to be delivered to a compliant display device. This presentation will cover the methodology and tools needed to properly approach and troubleshoot implementation challenges.

9463-9, Session 3

Interfaces, part two: implementation challenges of compressed video: transports streams over RF and IP

Karl J. Kuhn, Tektronix, Inc. (United States)

Interfaces- Part Two- Implementation Challenges of Compressed Video – Transports Streams over RF and IP

Maintaining quality of HD video and related meta-data and their associated issues are not always apparent in the digital domain. We can no longer just look at the video and listen to audio to determine all its signal quality aspects. Each layer of the underlying digital technology needs to be constantly monitored to see if you are moving closer to the "Digital Cliff".

This presentation will explain how to make sure your content adheres to the "rules of the road" and operates within interoperability requirements. This tutorial will be presented with a focus on the practical aspects you need to know to better understand testing methodology.

The practical aspects of the real life challenges in implementing compressed content over 8VSB and QAM for video, audio, and data distribution will be covered. It will address challenges such as timing issues concerning PCR (Program Clock Reference) inaccuracies, PCR jitter/drift, frequency offset, Error Vector Magnitude (EVM) , modulation error ratio (MER), Constellation Diagrams, and how they will impact the quality of the compressed contents delivery to the viewers.

IP Packet transport and delivery requires the system to be smooth and stable. If the packets are lost, duplicated, or out of sequence this severely impacts the Quality of Experience. The importance of monitoring packet timing and continuity counter errors will be discussed.

Multi-layer monitoring techniques based on TR101 290 measurement guidelines are primarily designed to check the integrity of an MPEG transport stream in an operational environment. The guidelines provide for three priority levels of ATSC compliance and decodability tests. This presentation will cover the methodology and tools needed to properly approach and troubleshoot implementation challenges.

9463-11, Session 4

Big data happiness *(Invited Paper)*

Andrew Eick, Mission Focus (United States); Suzanne Yoakum-Stover, Institute for Modern Intelligence (United States)

For most organizations, Big Data is an ocean of suffering. In this paper we discuss the root causes of this suffering (ambiguity and scale), methods for reducing it (refinement and unification), and practices to stop creating more of it (sustainable data operations and management). We also present a fully implemented compute and storage apparatus that embodies these methods and practices, which NGA calls the GeoInt Data & Analytics Cloud (GDAC). We describe how GDAC and motion imagery standards, quality, and interoperability reinforce each other to operationalize diverse data at scale, creating an ideal platform for ABI, and thereby transform an ocean of suffering into Big Data happiness.

9463-12, Session 4

Collaborative real-time motion video analysis by human observer and image exploitation algorithms

Jutta E. Hild, Wolfgang Krüger, Stefan Bruestle, Patrick Trantelle, Gabriel Unmüssig, Norbert Heinze, Elisabeth Peinsipp-Byma, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany); Jürgen

Beyerer, Fraunhofer Institute of Optronics, System Technologies and Image Exploitation (IOSB) (Germany) and Vision and Fusion Laboratory, Karlsruhe Institue of Technology (Germany)

Motion video analysis is a particularly challenging task, especially in real-time applications. On the one hand, over the last years, large progress has been made in the development of automated image exploitation algorithms. On the other hand, the human observer is an obligatory part of the complete analysis system in lots of security or safety critical applications. Our approach strives to combine both the qualities of the human observer's perception and the automated algorithms, thus aiming to improve the overall performance of a real-time video analysis system. We outline the advantages of both human and automated video analysis capabilities and show what benefit we expect to receive from such "collaborative" video analysis. We build on prior work where we showed the benefits the human observer receives by a user interface which utilizes the human visual focus of attention revealed by the eye gaze direction for interaction with the image exploitation system; eye tracker-based interaction allows much faster, more convenient, and equally precise moving target acquisition in video images than traditional computer mouse selection [1]. We also build on prior work on automated target detection, segmentation, and tracking algorithms [2]. We show how and for what types of tasks the information about the human observer's eye gaze direction and the results computed by the automated algorithms can be brought together in a beneficial way, and describe the challenges occurring with the design of such a collaborative system.

[1] Hild, J., Brüstle, S., Heinze, N., & Peinsipp-Byma, E. (2013, May). Gaze interaction in UAS video exploitation. In SPIE Defense, Security, and Sensing (pp. 87400H-87400H). International Society for Optics and Photonics.

[2] Teutsch, M., & Krüger, W. (2012, September). Detection, segmentation, and tracking of moving objects in UAV videos. In Advanced Video and Signal-Based Surveillance (AVSS), 2012 IEEE Ninth International Conference on (pp. 313-318). IEEE.

9463-13, Session 4

File-based video QC and automation in enterprise and cloud implementations

Karl J. Kuhn, Tektronix, Inc. (United States)

This presentation will be a tutorial on file based Quality Control for an onsite Enterprise system and also how it applies to video technology that is moving to a Cloud based workflow. The world of content QC has changed from being a tape based workflow with a QC person being able to keep up with the task of 100 percent QC to one with all content being transcoded to multiple formats. It has become impractical for a person with the Golden Eyes and Ears to have a one to one relationship with the ever expanding workload. This process needs to automated to better utilize the available QC staff allowing them to focus on files that do not meet acceptance and interoperability criteria.

Meeting the content's deliverable requirements is an important step in automating the QC process. The file needs to pass baseband acceptance criteria for blockiness, freeze frames, gamut, to also include audio level and channel configuration requirements to name just a few of possible pass/fail scenarios. Interoperability testing should be enabled to verify the wrapper compliance as well as drilling down to the compression layer for syntax errors.

This paper will cover transcoding, storage, and distribution in The Cloud and how to capitalize on its efficiencies. Media workflows are increasingly being migrated in the Cloud to take advantage of the instant scalability and usage-based pricing models of Cloud platforms that allow for highly elastic throughputs.

An automated QC process can interface with a Media Asset Management system that includes human readable and machine readable reporting. The human readable reports are Red Light/Green Light where the user can the drill down into the file down to the specific frame that triggered the error to determine a remedy. This presentation will walk thru the available tools to simplify this process of moving into a file based workflow with automated Quality Control.

9463-14, Session 5

CODEC optimization and referenced objective evaluation

Karl J. Kuhn, Tektronix, Inc. (United States)

CODEC Optimization and Referenced Objective Evaluation-- Optimizing the configuration of a Encoder is all about getting the highest quality at the lowest bitrate, so we need to implement a method of repeatable and objective optimization based on human vision sciences to obtain an acceptable Quality of Experience. This paper will focus on DMOS (Differential Mean Opinion Score), but will also touch upon PSNR (Peak Signal-to-Noise Ratio) and JND (Just Noticeable Difference) testing scenarios to explain available testing tools.

Picture quality in a compressed system can change dynamically based on a combination of data rate, picture complexity, and the encoding algorithm employed. The static nature of most test signals does not provide true characterization of picture quality. Human viewer testing has been traditionally conducted as described in ITUR Rec. BT.500-11. A test scene with natural content and motion is displayed in a tightly controlled environment, with human viewers expressing their opinion of picture quality to create a DMOS Score.

Extensive testing using this method can be refined to yield a consistent subjective rating. However, this method of evaluating the capabilities of a compressed video system can be inefficient, taking several weeks to months to perform the experiments. This test methodology can be extremely expensive to complete, and often the results are not repeatable. Thus, subjective DMOS testing with human viewers is impractical for the CODEC design phase, and inefficient for ongoing operational quality evaluation.

This paper will discuss a test mythology that is fast, practical, repeatable, and an objective measurement alternative to subjective DMOS evaluation of picture quality. These tools include the ability to apply a Region of Interest as well modeling for Attention, Perception, Viewing, and Display to assist in fine tuning the Device Under Test.

9463-15, Session 5

New long-zoom lens for 4K super 35mm digital cameras

Laurence J. Thorpe, Canon U.S.A., Inc. (United States); Fumiaki Usui, Canon Inc. (Japan); Ryuhei Kamata, Canon U.S.A., Inc. (United States)

Contemporary large-format single-sensor digital motion imaging cameras center largely about the image size of the Super 35mm 3-perf motion picture film format. An extensive global inventory of prime lenses exists that are widely deployed on these digital cameras. Zoom lenses are slowly becoming more popular and recent designs meeting 4K optical performance are spurring their further adoption. To date, however, the focal ranges of these zooms have been quite limited – certainly compared to what is presently available in the internationally standardized 2/3-inch B4 mount zoom lenses.

In the realm of broadcast television production – most especially in the documentary and sports genres – there is an increasing plea for Super 35mm 4K ultra-telephoto zoom lenses. The realities of this form of shooting entail the desirability of easy transportation of lens-camera-tripod systems, with the additional facility of shoulder-mount acquisition in remote and challenging environments. It is anticipated that there are some military and homeland security applications for this unique lens. The exhortation of the many international shooters of documentary programming was for such a lens to also be as compact and lightweight as possible. Paradoxically, large image format size, extended zoom range, and ensuring 4K optical performance – collectively tend to elevate overall lens size and weight.

This presentation will discuss the technical challenges entailed in the design of a new 4K Super 35mm zoom lens that offers an extended 20 times zoom range with a 1000 mm telephoto capability (augmented by a built-in 1.5x range extender to take this to 1500 mm). The lens maintains full 4K optical specifications over the entire focal range. A design goal was set of no more than 15 lbs weight and an overall length not to exceed 16 inches.

Fulfilling 4K aspirations entailed considerations of the MTF target for the image center and the attendant optical strategies to control the degree of lowering of that MTF toward the image extremities as well as its behavior over the zoom range. Two image zones and the success in meeting the target MTF performance within each will be discussed.

4K performance also significantly elevated the challenge in curtailing optical aberrations – both the monochromatic and the chromatic aberrations. Minimization of focus breathing and zoom tracking errors were a special priority. Design strategies to deal with these issues will be outlined. A major challenge imposed by application of severe strictures on size and weight of the zoom lens lay in achieving an acceptable maximum relative aperture and controlling the degree of ramping when the lens aperture is wide open.

Achieving all of the above called for multiple new technologies and techniques. The compensating strategies entailing combinations of different (and new) glass materials, use of aspheric lens elements, and novel element groupings, used to minimize these distortions will be explained.

A separate design challenge lay in the design of the compact lens-mounted precision servo drive system for operation of zoom, iris, and focus.

9463-7, Session 6

Automated content and quality assessment of full-motion-video for the generation of meta data

Joshua D. Harguess, Space and Naval Warfare Systems Ctr. Pacific (United States)

Virtually all of the video data (and full-motion-video (FMV)) that is currently collected and stored in support of missions has been corrupted to various extents by image acquisition and compression artifacts. Additionally, video collected by WAMI surveillance systems and UAVs and similar sources is often of low quality or in other ways corrupted so that it is not worth storing or analyzing. In order to make progress in the problem of automatic video analysis, the first problem that should be solved is deciding whether the content of the video is even worth analyzing to begin with. We address three types of scenes which are typically found in real-world data stored in support of DoD missions: no or very little motion in the scene, large occlusions in the scene, and fast camera motion. Each of these produce video that is generally not usable to an analyst or automated algorithm for mission support and therefore should be removed or flagged to the user as such. We utilize current state-of-the-art no-reference video quality algorithms, along with other computer vision advances in motion detection, to automatically assess FMV for the identification and generation of meta-data (or tagging) of video segments which exhibit unwanted scenarios as described above. Results are shown on simulated video as well as real-world video data.

9463-16, Session 6

A very low-cost system for capturing 3D motion scans with color and texture data

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

This paper presents a technique for capturing 3D motion scans using hardware that can be constructed for approximately $5,000 in cost. The system utilizes 50 networked raspberry pi single-board computers and cameras which are networked together using Cisco Ethernet switches to a central server which controls the capture process and receives the captured data when collection is complete. This system was initially designed to capture still images; however, it is now being expanded to also capture 3D video, as well.

This hardware-software solution, in addition to capturing the movement of the physical structures also captures color and texture data. This allows significant versatility in the use of the data, as well as allowing coloration to be utilized to mark points for tracking on a subject. Each frame can be utilized individually, to create a model, or as part of a 3D video scan. The scanner configuration developed at the University of North Dakota is sufficient in size for capturing scans of a group of humans.

The scanning process starts with synchronization, to ensure that frames can be correlated to each other. With all frames in the same time context, each frame can be individually modeled, in a similar way to how a single 3D model would be created. For many applications, an ordered collection of models will be sufficient or desirable. This, for example, facilitates analysis of deformation and movement between any arbitrary points in the capture duration. For some applications linking structural elements from frame-to-frame may also be required.

The paper, next, discusses the efficacy of this scanning approach. Various areas where the scanner could be used and the scanning approach's utility for these areas is considered. The paper then discusses future work, before concluding.

9463-17, Session 6

Projection of controlled repeatable real-time moving targets to test and evaluate motion imagery quality

Stephen D. Scopatz, Electro Optical Industries, Inc. (United States)

The projection of controlled moving targets is a key to quantitative testing of the video capture and post processing for Motion Imagery. This presentation will discuss several implementations of target projectors with moving targets or apparent moving targets creating motion to be captured the camera under test. The targets presented are broadband (UV-VIS-IR) and move in a predictable, repeatable and programmable way; several short videos will be included in the presentation. Among the technical approaches will be targets that move independently in the camera's field of view, as well targets that change size and shape. The development of a rotating IR and VIS 4 bar target projector with programmable rotational velocity and acceleration control for testing hyperspectral cameras is discussed. A related issue for motion imagery is evaluated by simulating a blinding flash which is an impulse of broadband photons in fewer than 2 milliseconds to assess the camera's reaction to a large, fast change in signal. A traditional approach of gimbal mounting the camera in combination with the moving target projector is discussed as an alternative to high priced flight simulators. Based on the use of the moving target projector several standard tests are proposed to provide a corresponding test to MTF (resolution), SNR and minimum detectable signal at velocity. Several unique metrics are suggested for Motion Imagery including Maximum Velocity Resolved (the measure of the greatest velocity that is accurately tracked by the camera system) and Missing Object Tolerance (measurement of tracking ability when target is obscured in the images). These metrics are applicable to UV-VIS-IR wavelengths and can be used to assist in camera and algorithm development as well as comparing various systems by presenting the exact scenes to the cameras in a repeatable way.

9463-18, Session 6

4K, ultra HD, and 8K realities

Karl J. Kuhn, Tektronix, Inc. (United States)

4K, Ultra HD, and 8K Realities- This session will be a tutorial on the 4K, Ultra HD, and 8K Realities with a focus on the practical aspects you need to know to maintain video quality and avoid the dreaded digital cliff. It will cover the fundamentals of the underlying technology at a depth that will allow you to build a solid foundation for your understanding of this layer.

When 720p and 1080i just are not good enough we find ourselves with new challenges of 4K and beyond. As the industry moves toward 4K, Ultra HD, and 8K this will bring new technology concerns. To transport the increased data rates two new interface types are needed- Quad Link and Interleaved video data is carried on four separate SDI cable connections. This requires tight control of timing issues between the four connections to maintain signal interoperability. Physical layer concerns are more important than ever in systems utilizing 3Gb/S Serial Digital Interfaces. This presentation will cover Eye and Demodulated Jitter testing of the physical layer to maintain system interoperability. Optical fiber implementations also bring new challenges.

Understanding various system adjustments using test gear is critical in ensuring a high quality image and preventing mistakes from occurring. This presentation will walk thru the available tools to simplify this process. It will cover waveforms, vectors, diamond, arrowhead, and lighting displays that have the capability of alarming and logging errors.

These comprehensive measurement capabilities enable users to reduce the time to isolate, diagnose and remedy system issues and design faults. Proper testing methodology is required from the end to end of R&D, equipment/system qualification, as well as operational troubleshooting aspects for installation and maintenance of content higher resolution video capture and distribution.

9463-19, Session 6

Gamut and camera shading

Karl J. Kuhn, Tektronix, Inc. (United States)

Gamut and Camera Shading-- This session will be a tutorial on the Gamut and Camera Shading with a focus on the practical aspects you need to know to maintain video quality and avoid the dreaded digital cliff. It will cover the fundamentals of the underlying technology at a depth that will allow you to build a solid foundation for your understanding of this layer.

Image quality begins at the source with gamut concerns for graphics and camera shading The conversion of light into electrical signals involves many processes which can affect the quality of the image. It all starts with the correct alignment of the camera which is used to capture the scene.

Gamut and Shading primarily deals with the luma adjustments of the signal, but it is also important to ensure the color fidelity of the image. To achieve this, an accurate test chart is required that produces a reference pattern. Typically the aim is to reproduce the image on a display monitor as closely as possible to the original scene without causing any interoperability issues in the system.

Understanding these various necessary adjustments using test gear is critical in ensuring a high quality image and preventing mistakes from occurring. This presentation will walk thru the available tools to simplify this process. It will cover waveforms, vectors, diamond, arrowhead, and lighting displays that have the capability of alarming and logging errors.

9463-22, Session 6

Use of KLV to combine metadata, camera sync, and data acquisition into a single video record

Paul Hightower, Instrumentation Technology Systems (United States)

This paper will explore how by combining recording metadata with precise camera sync and data acquisition strobes can result in a single video record where picture taking and data taking are all in lockstep. Lastly, metadata enables us to record clean video while retaining the ability to later place crosshairs, data and time during playback as desired.

Conference 9464: Ground/Air Multisensor Interoperability, Integration, and Networking for Persistent ISR VI

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9464-1, Session 1

Tasking the Tweeters: obtaining actionable information from human sensors

Alun D. Preece, William Webberley, Cardiff Univ. (United Kingdom); Dave Braines, IBM United Kingdom Ltd. (United Kingdom)

Twitter has proven itself a valuable medium for obtaining real-time information on breaking events, as well as a tool for campaigning. When tweeters can be characterised in terms of location (e.g. because they geotag their updates, or mention known places) or topic (e.g. because they refer to thematic terms in an ontology or lexicon) their posts can provide actionable information. Such information can be obtained in a passive mode, by simply “scraping” data from Twitter, but even greater value can be gained from an active mode of operation, by engaging with particular tweeters and asking for clarifications or amplifications. In this paper we show how this kind of sensing can be accommodated within an existing framework for sensor-task matching, by extending existing ontologies of sensors and mission tasks, and accounting for variable information quality. An integrated approach allows tweeters to be “accessed” and “tasked” in the same way as physical sensors (e.g. unmanned aerial and ground systems) and, indeed, combined with these more traditional kinds of source. We illustrate the approach using a number of case studies, including field trials (e.g. obtaining eyewitness reports from the scene of organised protests) and synthetic experiments (e.g. crowdsourced situational awareness).

9464-2, Session 1

Exploring discriminative features for anomaly detection in public spaces

Archan Misra, Singapore Management Univ. (Singapore)

No Abstract Available

9464-3, Session 1

Detection of anomalous track patterns for long term surveillance

Shuowen Hu, Prudhvi Gurram, Alex L. Chan, U.S. Army Research Lab. (United States)

No Abstract Available

9464-4, Session 1

Experiences with an anomaly determination services *(Invited Paper)*

Prasanna Giridhar, Tarek Abdelzaher, Univ of Illinois at Urbana-Champaign (United States)

The paper describes experiences with a service that searches social feeds for the most plausible explanation of a specific physical observation. A spike in traffic at midnight, for example, is not anomalous if it is explained by a rock concert that lets out at that time. It is anomalous if it is attributed to a gathering at the city hall outside typical business hours. We developed a prototype of such a search-and-explain service. Evaluation in the context of abnormal traffic interruptions in major California cities compares our automatically found explanations of the interruption to ground truth (from the Department of Transportation), showing a very high success rate at correctly explaining the physical observations. Some interruptions can thus be deemed “normal” (e.g., scheduled maintenance, football games, etc). Others are anomalous (e.g., bomb squad on scene). The paper discusses experiences with using this service to explain causes of different observations in order to determine whether an anomaly is at play. The service works by ranking social network feeds (e.g., from Twitter) by information gain; a metric that allows microblogs that are most exclusive to a time window of interest to be ranked on top. These high-ranking microblogs are further filtered by location keywords to determine those that are specific to a given locale. Finally, they are filtered by statistical credibility metrics. The result is used to reliably explain what the social network says about events at a given time and location. The explanation can then be compared to a database of “normal explanations” to determine if the cause of an unusual behavior is “normal” or not.

9464-5, Session 1

The use of visual programming tools and techniques for rapid in field situational application development in a coalition environment *(Invited Paper)*

David Conway-Jones, IBM United Kingdom Ltd. (United Kingdom)

The use of visual programming tools and techniques for rapid in field ad-hoc edge of the network situational application integration in a coalition environment.

The recent upsurge in so called “Internet of Things” technologies, solutions and products has brought with it a plethora of new tools to exploit them. Among these there are some more visual tools that provide a “flow based programming” (1) model. These would seem to be applicable to the in-field environment where integration of pre-configured “blocks” can lead to fast results, with higher accuracy than traditional programming techniques. One of these, Node-RED (2) has been deployed and used in a UK MoD Land Open Systems Architecture (LOSA) field trial (Oct 20124).

This paper describes how the use of the Node-RED visual wiring tool, allowed very fast integration of networked assets during a field trial. These included individual sensors, gateways to soldier systems, and access to a Nato coalition partner’s assets (vehicle, soldiers and micro-uav).

1) https://en.wikipedia.org/wiki/Flow-based_programming)

2) http://nodered.org

9464-6, Session 2

Unified vision: NATO trials for ISR interoperability technologies *(Invited Paper)*

David L. Payton, U.S. Air Force (United States)

No Abstract Available

9464-7, Session 2

Standards-based MASINT ISR workflow overview

Eric Chen, Air Force Research Lab. (United States)

No Abstract Available

9464-8, Session 2

Networks sensing and adaptive processing: vision and challenges

Gavin Pearson, Defence Science and Technology Lab. (United Kingdom)

Achieving the required granularity (inc. discrimination), volume and persistence of Surveillance, Target Acquisition and Reconnaissance (STAR) will continue to rely on the co-ordinated use of a mixture of sensor types operating across and beyond the electro-magnetic spectrum mounted on a disparate array of platforms (including bases). Exploiting such a network of synergistic sensors whilst dealing with the volume, velocity and variety of resulting data and time critical nature of many STAR tasks requires a networked bi-directional adaptive, distributed data processing system.

This paper describes such a system and places it within the context of developments such as distributed tactical service buses, micro-clouds, content based networking, model driven architecting and data mining. As such it represents an update on an earlier paper published at SPIE DSS in 2008 (6963-1). Finally the paper discusses some of the key challenges if such a system is to be fully realised.

9464-9, Session 3

Policy controlled access to analytics at the network edge

Geeth de Mel, Jorge J. Ortiz, Seraphin Calo, IBM Thomas J. Watson Research Ctr. (United States); Paul Sullivan, Intelpoint, Inc. (United States)

Coalitions operate in dynamic environments where in-situ information sources are distributed. Analyses performed over this data equip end-users with improved situational awareness so they can make informed decisions in a given context. However, due to various constraints (e.g., bandwidth, energy, and so forth), it is not prudent to assume that analyses could always be performed centrally. Moreover, units belonging to coalitions are typically entrusted with specific tasks. Thus, units may typically only carry specific analytics associated with those tasks. However, due to the dynamism in the field, different analytics may be needed on-the-fly from the coalition network. Thus, mechanisms to discover and execute analytics at the network edge from coalition network, while respecting a coalition's policy constraints in a decentralized fashion, is necessary. Our recent work on bringing computation to data – i.e., Microcloud – could be useful in addressing this issue as we could move decision procedures to the edge users based on their needs. The work presented in this document augments the Microcloud work with policy capabilities so that coalition interoperability is enabled.

9464-10, Session 3

Computing on encrypted data and its applicability to a coalition operations environment

Flavio Bergamaschi, Graham Bent, IBM United Kingdom Ltd. (United Kingdom)

Computing on encrypted data is the ability to perform computations on data whilst it is in its encrypted form. Fully Homomorphic Encryption (FHE) provides such capability.

Coalition operations often invoke the sharing of information and IT infrastructure amongst partners, but it is limited by te requirement of not revealing classified data. Ideally, coalition partners would wish to share data that can be used to compute specific results that are only relevant to a given operation without revealing all of the shared information.

In this talk we will present the fundamentals of FHE, discuss its potential uses and pitfalls in a coalition operations environment, and the results of a practical implementation using FPGA hardware acceleration..

9464-11, Session 4

The convergence of open systems and interoperable systems

Gavin Pearson, Defence Science and Technology Lab. (United Kingdom); John B. Ibbotson, IBM United Kingdom Ltd. (United Kingdom)

This paper sets out the case that technical ISR (Intelligence, Surveillance and Reconnaissance) System Interoperability is a sub-set of more general Open and Modular Information System design; both address the same architectural issues associated with layers, templates, interface specification, profiles, data models, process control and assurance.

The paper illustrates its argument by reference to the UK Ministry of Defence Land Open System Architecture (LOSA) and NATO ISR STANAGs. The paper concludes with a framework to enable those ISR specialists concerned with interoperability to engage with those concerned with open and modular information system infrastructures.

9464-12, Session 4

PED fusion via enterprise ontology

James R. Schoening, Danielle Duff, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States); Tien Pham, U.S. Army Research Lab. (United States); Ronald Rudnicki, CUBRC (United States); Gary H. Stolovy, Jeff Houser, U.S. Army Research Lab. (United States); Alex James, Eric Nagler, CUBRC (United States); Dorothy A. Hines, Keith M. Riser, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States); Robert Ganger, CUBRC (United States)

Processing, Exploitation, and Dissemination (PED) requires on-board fusion of any number of disparate sensors and other data sources. This paper and presentation reports on a series of success technology demonstrations of how a common ontology can be used to transform intelligence data from disparate sources into logically consistent triples, which can then be fused using inferencing, entity and event resolution, and other 3rd party analytic apps that can access and understand this normalized data via only one API.

The PED thrust in DOD is necessitated by the exponential growth in sensor data output and the inability of slow growing tactical bandwidth to transmit this data to higher echelons for processing, exploitation, and dissemination. These functions must be done as close to the sensor as possible, even on-board a UAV or vehicle.

A key enabling technology is the automated fusion of any number of disparate data sources. While any given UAV mission my require fusion of just a few sensor data sources, which can be accomplished with prior point-to-point integration, this approach does not scale, since the range of all missions will require the combination of any number of data sources.

This paper and presentation introduces the I2WD Ontologies, which describe the entities in reality sensed by sensors, and can be extended to include any level of detail required by current or future sensors. It reports

how a wide variety of sensor and other data sources, including motion video, radar, track, position-location, acoustic, natural language text, and structured data have all been transformed (i.e. normalized) into conforming triples. While we have demonstrated how a number of analytics can fuse this data, the breakthrough is how small 3rd party analytic apps can access all transformed data from all sources via just one API, and how these apps can be selected and combined for unique objectives.

9464-13, Session 4

The Sandia architecture for heterogeneous unmanned system control (SAHUC)

Joshua A. Love, Wendy Amai, Sandia National Labs. (United States); Timothy Blada, Sandia National Labs (United States); Charles Q. Little, Jason Neely, Stephen Buerger, Sandia National Labs. (United States)

The Sandia Architecture for Heterogeneous Unmanned System Control (SAHUC) was produced as part of a three year internally funded project performed by Sandia's Intelligent Systems, Robotics, and Cybernetics group (ISRC). ISRC created SAHUC to demonstrate how teams of Unmanned Systems (UMS) can be used for small-unit tactical operations incorporated into the protection of high-consequence sites. Advances in Unmanned Systems have provided crucial autonomy capabilities that can be leveraged and adapted to physical security applications. SAHUC applies these capabilities to provide a distributed ISR network for site security. This network can be rapidly re-tasked to respond to changing security conditions.

The SAHUC architecture contains multiple levels of control. At the highest level a human operator inputs objectives for the network to accomplish. The heterogeneous unmanned systems automatically decide who can perform which objectives and then decide the best global assignment. The assignment algorithm is based upon coarse metrics that can be produced quickly. Responsiveness was deemed more crucial than optimality for responding to time-critical physical security threats. Lower levels of control take the assigned objective, perform online path planning, execute the desired plan, and stream data (LIDAR, video, GPS) back for display on the user interface. SAHUC also retains an override capability, allowing the human operator to modify all autonomous decisions whenever necessary.

SAHUC has been implemented and tested with UAVs, UGVs, and GPS-tagged blue/red force actors. The final demonstration illustrated how a small fleet, commanded by a remote human operator, could aid in securing a facility and responding to an intruder.

9464-14, Session 4

Dual node decision wheels: an architecture for interconnected information fusion and decision making

Amy L. Sliva, Joe Gorman, Charles River Analytics, Inc. (United States); Christopher L. Bowman, Data Fusion Corp. (United States); Martin Voshell, Charles River Analytics, Inc. (United States)

As the modern information environment continues to expand with new technologies, military Command and Control (C2) has increasing access to unprecedented amounts of data and analytic resources to support military decision making. However, with the increasing quantity and heterogeneity of multi-INT data—from new collection platforms, new sensors, and new analytic tools—comes a growing information fusion challenge. Increasingly distributed processing, exploitation, and dissemination (PED) capabilities and analyst resources must identify and integrate the most relevant data sources for improving operational command and control and situation awareness without becoming overwhelmed and potentially missing critical information.

In this paper, we present an innovative new information fusion and organizational decision making architecture—Dual Node Decision Wheels (DNDW)—that integrates PED, analysis, and C2 processes through a novel combination of goal-directed information fusion and data-driven decision making, helping alleviate "big data" challenges through more fluid coordination of organizations and technologies. DNDW applies the dual node network (DNN) technical architecture for data fusion and resource management (DF&RM), and extends this architecture with explicit associations to organizational processes and supported decision aides. Using semantic technologies to link the operational context with available data resources, DNDW ensures that each organizational role has access to the information or tools that will best support the mission. This approach represents a fundamentally new perspective on both information fusion and organizational decision making, viewing these not as distinct phases in an operational pipeline, but as highly interconnected processes. We describe the technical attributes of DNDW and provide guidance for real-world implementation. Case study analyses illustrate how DNDW can map fusion onto any organizational structure and provide a cost-effective "plug and play" environment for integrating new technologies.

9464-15, Session 5

Acoustic sensor network for hostile fire indicator for ground bases and helicopter-mounted applications

Pierre Naz, Sebastien Hengy, Martin Laurenzis, Institut Franco-Allemand de Recherches de Saint-Louis (France)

This paper briefly describes the set-up of the sensors and the instrumentation deployed by the French-German Research Institute of Saint-Louis (ISL) during experiment trial performed during the last year.

First we will present results gained during the last NATO/ACG3/SG2 HFI Threat Data Collection (conducted during the summer 2014 in Czech Republic). The main purpose of this trial was the measurement of weapon and ammunition signature for threat warning / hostile fire indicator (HFI) system development. Weapons vary from small caliber rifles to anti-tank rockets in ground-to-ground shooting configurations. For the ISL team, the objective consisted in measuring the acoustic signals for detection and localization of weapon firing events. Experimental results of sound waves obtained using ground based sensors are presented and analyzed for shots obtained in various conditions.

This work is included in national/international efforts for the development of Hostile Fire Indicator for helicopters and ground bases taking into account small caliber guns, RPG, rockets and/or missiles.

For small caliber weapons, acoustic detection may provide valuable and complementary data to increase the protection capabilities of camps, convoys or helicopters.

For ground bases imaging systems have been combined with acoustical sensors in order to provide complementary information and better permanent surveillance. An experiment has been organized at the ISL proving ground within the context of the project "IMOTEP" to test new improvement in the detection of snipers on the battlefield (i.e. for ground sensors). Our basic approach is to combine several sources of information for a fast and appropriate reaction when an unusual signal (e.g. a flash or a shot) is detected. The project includes several technologies developed at ISL: acoustical detection, fusion of distributed sensor data, active imaging and 3D audio restitution of the threat.

9464-16, Session 5

The effect of decentralization and communication networks on a set of ISR-gathering assets

Héctor J. Ortiz-Peña, CUBRC (United States); Michael J. Hirsch, ISEA TEK (United States) and Stetson Univ. (United States); Mark H. Karwan, Univ. at Buffalo (United States); Moises Sudit, CUBRC (United States) and Univ. at Buffalo (United States)

Synchronization of Intelligence, Surveillance, and Reconnaissance (ISR) activities to maximize the utilization of limited resources (both in quantity and capabilities) has become critically important to military forces. In centralized frameworks, a single node is responsible for determining and disseminating decisions (e.g., tasks assignments) to all nodes in the network. This requires a robust and reliable communication network. In decentralized frameworks, processing of information and decision making occur at different nodes in the network, reducing the communication requirements.

This research studies the degradation of solution quality (i.e., information gain) as a centralized system synchronizing ISR activities moves to a decentralized framework. We extended the mathematical programming model presented in [1] for multi-perspective optimization in which each collection asset develops its own decisions to support mission objectives based only on its perspective of the environment (i.e., potential information gain). We consider different communication network topologies. Collection assets are part of the same communication network (i.e., a connected component) if: (1) a fully connected network exists between the assets in the connected component, or (2) a path (consisting of one or more communication links) between every asset in the connected component exists. Multiple connected components may exist among the available collection assets supporting a mission. We assumed information is only exchanged when assets are part of the same network. The potential location of assets that are not part of a connected component are considered (with a suitable decay factor as a function of time) as part of the optimization model.

9464-17, Session 5

Exploring EO Vehicle Recognition Performance using Manifolds as a Function of Lighting Condition Variability

Olga Mendoza-Schrock, Air Force Research Lab. (United States); Mateen M. Rizki, Wright State Univ. (United States)

Novel techniques are necessary in order to improve the current state-of-the-art for Assisted Target Recognition especially for persistent ISR. A fundamental flaw that current Assisted Target Recognition systems make is to assume that operating conditions stay semi-consistent between the samples that the system was used to train with and the testing samples. Today systems are still not robust to every day occurrences such as changes in lighting conditions. In this work, we explore the effect on vehicle recognition performance as lighting conditions are systematically changed. We explore low-dimensional nonlinear representations of high-dimensional data derived from electro-optical synthetic vehicle images using Diffusion Maps. Diffusion maps have been shown to be a valuable tool in the analysis of high-dimensional data and the technique is able to extract an approximation for the underlying structure inherent to the data. Our analysis includes examining the relationship between Euclidean pixel distance and Euclidean diffusion distance. We present recognition performance as a function of lighting condition. Additionally we describe a novel methodology to exploit the pixel distance vs. diffusion distance relationship to improve Assisted Target Recognition most importantly under situations where the training and testing samples are not obtained under the same lighting conditions for example.

9464-18, Session 6

Situational awareness: a holistic perspective your mother was afraid to tell you *(Invited Paper)*

Michael A Kolodny, U.S. Army Research Lab. (United States)

No Abstract Available

9464-19, Session 6

Automatic video-based classification of small group behavior to support situational understanding

Robert Williams, Air Force Research Lab. (United States); Julie A. Skipper, Skipper Consulting (United States)

Many metropolitan cities in the United States have implemented networks of surveillance cameras to improve crime prevention and forensics, protect public workers, and reduce the staff needs for city-wide monitoring. In addition to their utility in documenting and prosecuting crime, the collected data may be valuable in detecting emergent behavior. Of particular interest are the actions of small, transient groups of people and their interactions with other individuals, groups, and the environment. AFRL and ARL are collaborating to develop the capability to autonomously analyze surveillance video data and label group behavior as belonging to one of a defined number of classes (e.g., loitering, purposeful walking, celebratory behavior, nefarious activity, etc.). Broadly, the process will consist of the following steps: detection of groups of humans in a scene, where groups are defined as three or more people; group trajectory tracking, to include splitting and/or merging with other groups or individuals; human action recognition; and behavior labeling. Leveraging this framework, the coded video data can then be compared to expected temporal and spatial norms to identify anomalous events. Finally, these events can be combined with contextual information, particularly from social media, to support situational understanding.

9464-21, Session 7

Ground target tracking and classification in a unattended wireless sensor network

Benjamin Pannetier, Jean Dezert, Julien Moras, ONERA (France); Loic Canevet, Didier Cosson, Delegation Generale Pour L'Armament (France)

In this paper, we address the problem of multiple ground target tracking and classification with data from a unattended wireless sensor network. A multiple target tracking algorithm, taking into account the road and vegetation information, is studied in a centralized architecture. Despite of efficient algorithms present in literature, we must adapt to a basic approach to satisfy embedded processing. The algorithm enables tracking human and vehicles driving both on and off road. Base on previous work, we integrate road or trail width and vegetation cover, in motion model to improve performance of tracking under constraint. It also presents different dynamic models, to palliate the manoeuvres of targets including a stop motion model. In order to handle realistic ground target tracking scenarios, the tracking algorithm is integrated into an operational platform (named fusion node) which is an autonomous smart computer abandoned in surveillance area. After calibration step of the heterogeneous sensor network, our system is able to handle real data from a wireless ground sensor network. The performance of system is evaluated in a real exercise for Forward Operating Base (FOB) protection and road surveillance.

9464-22, Session 7

Feature extraction and classification using neurosynaptic processing at the edge of the network

Flavio Bergamaschi, Graham Bent, IBM United Kingdom Ltd. (United Kingdom)

The widespread use of sensors and sensor network, whether mobile or static, in tactical environments has demanded new types of technologies to overcome the requirements for communication bandwidth, power, local vs remote vs distributed processing of information, difficult of access sensor sites, local feature extraction , etc.

Research funded under DARPA's Systems of Neuromorphic Adaptive Plastic Scalable Electronics (SyNAPSE) program developed a new brain-inspired neurosynaptic computational architectures named TrueNorth that is low power and compact like an organic brain. TrueNorth comprises a scaleable network of configurable, neurosynaptic cores that is particularly suitable for implementing algorithms for sensor and actuator systems.

In this paper we will present an introduction the the TrueNorth architecture, the recent experimental results and discuss the uses of this technology to perform tasks like feature extraction and classification of sensor data at the edge of the network while complying with the requirements of unattended and unmanned sensors and sensor networks.

9464-23, Session 7

UAV as a generic information provider in an ISR System of Systems

Jurgo Preden, Jaanus Kaugerand, Erki Suurjaak, Raido Pahtma, Sergei Astapov, Leo Motus, Tallinn Univ. of Technology (Estonia)

Modern ISR systems present many challenges, which are related to what is called the Big Data problem but also with optimal resource utilization, especially in coalition operations. With proliferation of cost effective technologies, ground sensor systems can be deployed in volumes, enabling acquisition of large amounts of data, so the challenge of utilization of data rises. Optimal utilization of sensor assets is a challenge presented by high value sensor assets with advanced capabilities. Data to Decision (D2D) is a concept that can be applied both for managing sensor assets that are high value and have low availability as well as for sensor assets that are able to provide large amounts of information. The D2D concept proposes that the information needs of the information user are propagated to the sensor systems, which adjust their behaviour (including data acquisition and processing) according to the information needs to deliver the requested data with minimal resource requirements.

The paper presents an approach for coordinating sensor assets by using information requests to the sensor system, without central coordination. Instead the information consumers submit the requests for information to the sensor system and the sensor assets perform necessary data acquisition and processing, engaging additional data sources in case multi source fusion or triggering of sensors is used. The information request is directed to the area, from where information is needed, engaging the sensor assets in that area, which effectively means that the information needs are pushed to the edge of the network, to the individual sensor systems. Naturally this approach assumes that the sensor systems are autonomous and capable enough to process the high-level information requests (e.g., detect certain types of vehicles in a certain area, notify if movement not typical to that area occurs) and then deliver the requested information to the consumer. In such a setting the temporal and spatial aspects of data become important as the relationships between data providers and consumers are dynamic. also information is created in the field by the sensors, instead of communicating data to servers.

As the specific assets available in an area are not known, the available assets are engaged in an opportunistic manner. The ground based sensor assets also engage an autonomous UAV to provide additional data if an object of interest has been detected. The data collected by ground sensors and the UAV is combined by the data collected on the ground. The resulting information is communicated to the information consumer that originally requested the information. We use a proactive middleware ProWare for implementing the concept of dynamic data exchange between systems in the field. The paper presents the research results tha have been obtained by the end of the first year of the European Defense Agency project IN4STARS, which is concerned with information interoperability in coalition operations.

9464-24, Session 7

A micro services architecture for use by microcontroller driven devices to provide interoperability with the open lean services architecture

Nicholas Peach, 2iC Ltd. (United Kingdom)

In this paper we propose a technical solution that provides microcontroller-scale devices with compatibility to the open-standard lean services architecture used in the UK MoD Land Open Systems Architecture. The paper describes how low powered microcontrollers can achieve interoperability by using the lean services on-the-wire binary format. We show how the use of the micro services architecture by microcontroller devices increases the number of systems available for integration by a factor of 20, providing interoperability from the largest enterprise system down to tiny devices in the tactical environment using a single and consistent technique. We speculate on the consequences of all electronic devices deployed in the operational and tactical space now being available for open battlefield-wide interoperability.

The variations between the lean services architecture and the micro services architecture are described. The rational is explained for the decisions made in adapting to the very low computing power available in some microcontrollers. The described technique provides; a) service orientated architecture interoperability for microcontroller-level devices; b) compatibility with the lean services architecture; c) compatibility with LOSA allowing microcontroller devices to interoperate with other LOSA systems both on a local area network and across tactical radio links; d) roadmap for future enhancements; e) software toolkits to allow manufacturers to integrate the micro services architecture into their microcontroller driven devices.

The architecture re-uses existing lean services techniques and leverages the UK MoD Generic Soldier Architecture and LOSA.

9464-25, Session 7

Visibility based multi-agent surveillance strategies in decentralized network

Rui Zou, Sourabh Bhattacharya, Iowa State Univ. (United States)

In this paper, we address the problem of decentralized visibility-based target tracking for a team of mobile observers trying to track a team of mobile targets. Based on the results of previous work, we present the notion of pursuit fields around a single corner. We use the pursuit fields to generate navigation strategies for a single observer to track a single target in general environments. We extend this problem to the scenario when multiple observers and targets with incomplete communication graph are present. We propose a two level hierarchical approach. At the upper level, each observer is allocated to a target through a local minimum cost matching. At the lower level, each observer computes its navigation strategy based on the results of the single observer-single target problem, thereby, decomposing a large multi-agent problem into several 2-agent problems. Finally, we evaluate the performance of the proposed strategy in simulations and experiments.

9464-26, Session 8

Bayesian hidden Markov models for UAV-enabled target localization on road networks with soft-hard data

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This work addresses the problem of localizing a mobile intruder on a road network with a small UAV via fusion of event-based `hard data', collected from a network of unattended ground sensors (UGS), and `soft data', provided by human dismount operators (HDOs) whose statistical characteristics may be unknown. Current approaches to road network intruder detection/tracking have two key limitations: predictions become computationally expensive with highly uncertain target motions and sparse data, and they cannot accommodate uncertain sensor parameters. This work shows that these issues can be addressed in a practical and theoretically sound way using hidden Markov models (HMMs) within a comprehensive Bayesian framework. A formal procedure is derived for automatically generating sparse Markov chain approximations for target state dynamics based on standard motion assumptions. This leads to efficient online implementation for non-Gaussian localization aboard small UAV platforms via fast matrix operations, and also leads to useful statistical insights about stochastic target dynamics that could be exploited by intelligent UAV guidance and control laws. The computational efficiency of the HMM is then leveraged to address the problems of fusing uncertain HDO soft sensor data via hierarchical Bayesian estimation in the form of Rao-Blackwellized particle filtering. Simulation results are provided to demonstrate the validity and utility of the proposed Bayesian HMM tracking approaches.

9464-27, Session 8

Corrected pose data for the Wright Patterson Air Force Base (WPAFB) 2009 wide area motion imagery (WAMI) data set

Curtis Cohenour, Ohio Univ. (United States); Rebecca L. Price, U.S. Air Force (United States); Todd V. Rovito, Air Force Research Lab. (United States); Frank van Graas, Ohio Univ. (United States)

The WPAFB 2009 Wide Area Image Data Set consists of 1537 frames of high resolution image data. The data is supplied as raw images with pose files, and also as projected images in National Imagery Transmission Format (NITF). The georegistration performance of the NITF images is 22.3 m Root Mean Square Horizontal (RMSH). In a previous paper calibrated camera models were developed to reduce the georegistration error to 3.3 m RMSH. In this work corrected pose files are generated to reduce the error to 0.9 m RMSH. This is done by correcting the pose errors in a stepwise fashion to illustrate the error sources, which are: GPS position bias, time registration errors, and attitude errors. The pose files are then corrected by simultaneously modifying the position and attitude to achieve the 0.9m RMSH result. The corrected pose files are posted to allow users to perform high accuracy projection, tracking, and other functions.

9464-28, Session 8

Classification of vibrometry data

Karmon M. Vongsy, Air Force Research Lab. (United States); Ashley N. Smith, Wright State Univ. (United States)

Laser vibrometry provides a method to identify running vehicles' unique signatures using non-contact measurements. A vehicle's engine, size, materials, shape, and more vary its signature. To classify and identify these signatures, a robust aided target recognition (AiTR) end-to-end process is evaluated and expanded. Several challenges arise when classifying vehicles' vibration signatures. Operating conditions, parameters that vary such as weather, terrain, sensor location, sensor type, and engine speed, present the main challenge. Another challenge in vehicle classification is the determination of signal features that can overcome the differences created by these varying operating conditions. Eleven features taken from automatic speech recognition, seismology, and structural analysis were used in this end-to-end process. Features were selected by two feature selection methods to determine the best feature set for vehicle classification. Finally, four classifiers were used to identify vehicles' signatures. The classifiers' confusion matrices were used to make decisions on the end-to-end process. The entire process was tested on two small in-house data sets: a military vehicle collection using accelerometers and a civilian vehicle collection using a laser vibrometer and accelerometers.

9464-29, Session 8

Predicting exploitation success on compressed imagery through common image quality metrics: an initial look

Christopher McGuinness, Univ. of Dayton Research Institute (United States)

Imagery from unmanned aerial systems (UAS) needs compression prior to transmission to a remote processing station for exploitation. Exploitation on imagery, such as frame-to-frame registration, target tracking, and target identification, is performed to extract information from the data. In target-rich environments, it is often necessary that these algorithms be performed automatically. Unfortunately, in a compress-then-analyze system, the analysis performed on the data must contend with artifacts introduced by compression, assuming lossless transmission. Identifying metrics that allow compression engines to predict exploitation degradation could allow encoders the ability of tailoring compression for exploitation. This study assesses the impact of H.264 compression on target tracking through common tracking metrics while measuring image quality using common image metrics.

9464-30, Session 9

Real-time algorithms for data reduction and smart sensing with high frame rate CMOS image sensor

Blake C. Jacquot, Nathan G. Johnson-Williams, The Aerospace Corp. (United States)

Both CMOS image sensors and available computing resources have advanced in recent years to the point where new data collection methods are possible and necessary. Possible methods include real-time algorithms for automatic detection of targets of interest. Necessary methods include algorithms to perform preliminary data reduction for high-frame rate sensors. With space systems both are desirable to accommodate limited transmission bandwidth, limited link availability, and limited storage capacity. In particular, high-frame rate sensors produce more data than can be transmitted to ground. Space-based high-frame rate sensing holds the possibility of opening new sensing paradigms, but realizing the potential requires new sensing schemes.

Real-time algorithms can address computation and bandwidth issues for high-frame rate sensors by locally implementing algorithms and transmitting a reduced relevant data set. Implementation requires significant computing power and judgment in order to maintain high quality standards. The system (FPGA and host processor) must capture, analyze, and store every pixel according to algorithm constraints without dropping frames. Further, the system must effectively run closed loop, where trigger events determine what data is stored for transmission and what is discarded. This significantly departs from standard open-loop operation for traditional sensor systems.

To further understanding of how real-time algorithms can benefit high-frame rate systems, we present results of real-time algorithms demonstrated on a custom system. The system is built around a commercial CMOS image sensor with 1280 ? 1024 format, 10-bits per pixel, global shutter, non-destructive read (NDR), and frame rates of 0.5 kHz to 100 kHz.

9464-31, Session 9

Beyond H.264: implications of next generation video compression on surveillance imagery

Christopher McGuinness, Univ. of Dayton Research Institute (United States)

Unmanned aerial systems (UAS) equipped with electro-optic (EO) full motion video (FMV) sensors often need to transmit the imagery over a limited communications channel, requiring either intense compression, reduced frame rate, or downsampled imagery to reach the receiver at adequate quality. In an attempt to improve rate-distortion performance of common video compression algorithms, such as H.264/AVC, several groups are developing compression methods to improve video quality at low bitrates. Concepts of these “next generation” methods, including H.265/HEVC, Google’s VP9, and Xiph’s Daala are examined in contrast with state of the art methods, such as H.264/AVC, BBC’s Dirac, and Motion-JPEG2000 within the context of aerial surveillance. Due to many of these methods being incomplete, it is premature to provide a full rate-distortion comparison of these methods, but data is provided for released standards.

9464-32, Session 9

Binocular link for smartphone (BLINKS) demonstration

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Analog binoculars lack recording capability. Linking analog binoculars with smartphones, live images captured in binocular can be recorded digitally as video in real time and transferred. Added capabilities, such as, additional zoom and GPS locating, wireless communication, etc, are possible. The linking of Commercial Off-The-Shelf (COTS) smartphones with analog binoculars has shown enormous potential including persistent ISR capability. The paper discusses the demonstration, results and lessons learned of BLINKS applications.

9464-33, Session 9

Phased array beamformer performance in variable environments

David R. Bergman, Exact Solution Scientific Consulting LLC (United States)

Beamforming techniques are used to locate sources and scattering centers from data acquired by either passive or active phased arrays. The technique has a wide variety of applications from far field source location and tracking to near field imaging. The presence of inhomogeneities in the environment will have an effect on the propagation of the field. This in turn will change the results of a beamformer prediction. Using simulated sources and environments one can systematically study the effect of the atmosphere on the angle of arrival as seen by the array. From these studies attempts at systematic corrections can be tested to evaluate their fidelity in a real system. We present the results of a series of studies on an acoustic field in the presence of sound speed fluctuation and steady wind profiles and demonstrate how various terms in environment contribute to changes in beamformer processing results.

9464-34, Session 9

Classification of uncooperative vehicles with sparse laser Doppler vibrometry measurements

Jie Wei, Chi-Him Liu, Zhigang Zhu, The City College of New York (United States); Olga Mendoza-Schrock, Karmon M. Vongsy, Air Force Research Lab. (United States)

Recently Laser Doppler Vibrometry (LDV) has been widely employed to achieve long-range sensing for the purpose of Intelligence, Surveillance and Reconnaissance (ISR) in military applications due to its high spatial and spectral resolutions in vibration measurements that facilitates effective analysis using signal processing and machine learning techniques. Collaborating with researchers in the Air Force Research Laboratory in the last several years, we have developed a bank of algorithms to classify different types of vehicles, such as sedans, vans, pickups, motor-cycles and buses, and identify various kinds of engines, such as Inline-4, V6, 1- and 2-axle truck engines. Thanks to the similarities of the LDV signals to acoustic and other time-series signals, a large of body of existing approaches in literature has been employed, such as speech coding, time series representation, Fourier analysis, pyramid analysis, support vector machine, random forest, neural network, and deep learning algorithms. We have found that the classification results based on some of these methods are extremely promising. For instance, our vehicle engine classification algorithm based on the pyramid Fourier analysis of the engine vibration and fundamental frequencies of vehicle surfaces over the data collected by our LDV in the summer of 2014 consistently attained 97% precision.

In laboratory studies or well-controlled environments, a great array of high quality LDV measured points all over the vehicles are permitted by the vehicle owners, therefore intensive classifier training can be conducted to effectively capture the innate properties of surfaces in the space and spectral domains. However, in real contested environments that are of utmost interest and practical importance to military applications, the uncooperative vehicles are either fast moving or purposively concealed and thus not many high quality LDV measurements can be made. In this work an intensive study is performed to compare the performance in vehicle classifications under the cooperative and uncooperative environments via LDV measurements based on a content-based indexing. The method uses an iterative Fourier analysis and an artificial feed-forward neural network. As our empirical studies have suggested, even in uncooperative and contested environments, with adequate training dataset for similar vehicles, our classification approach can still yield promising recognition rates.

9464-35, Session 9

Sources of uncertainty in feature-based image registration algorithms

Paul Sundlie, Joseph Fernando, Univ. of Dayton Research Institute (United States); Clark N. Taylor, Air Force Research Lab. (United States)

One significant technological barrier to enabling multi-sensor integrated ISR is obtaining an accurate understanding of the uncertainty present from each sensor. Once the uncertainty is known, data fusion, cross-cueing, and other exploitation algorithms can be performed, but these algorithms depend on the availability of accurate uncertainty information from each sensor.

In many traditional systems (e.g., a GPS/IMU-based navigation system), the uncertainty values for any estimate can be derived by carefully observing or characterizing the uncertainty of its inputs and then propagating that uncertainty through the estimation system. Using inertial measurement units as an example, the gyroscope and accelerometer sensors can be carefully characterized for noise, yielding a covariance matrix for the inputs. This covariance matrix, when used in a Kalman filter to combine the different measurements, will result in a output covariance that accurately represents the uncertainty of the output.

Feature-based image registration, on the other hand, cannot have its uncertainty characterized in this fashion. These algorithms generally consist of three basic steps. First, features are found in both images being registered. Second, features are matched between the two images, yielding correspondences. Finally, a model is chosen that best fits the different correspondences found. The difficulty with correctly estimating the uncertainty in these algorithms is that the inputs are not simple sensor measurements, so they are difficult to characterize. While the signal to noise ratio of an imaging sensor can be observed, the relationship of this noise with the feature location determined by feature identification algorithms is unclear. In addition, it will depend not only on the sensor itself, but on what data is being observed by the sensor (i.e. a smooth scene will have more error in its feature location than a rich scene.) Therefore, the input uncertainty for image registration is very difficult to characterize. In addition the algorithms themselves that are typically used to perform image registration do not propagate uncertainty in an intuitive way through the algorithm.

In this paper, we present results of an in-depth analysis of feature-based image registration uncertainty. We describe three sources of error in an image registration algorithm (input noise, outlier handling, and the RANSAC algorithm). Monte Carlo results demonstrating the effect of each of these sources of error are presented, and the impact these results have on how we model image registration uncertainty is discussed.

9464-36, Session 9

Ultra-wideband 3D position referenced environment for enhanced detection, marking, neutralization and change detection

David J. Bruemmer, 5D Robotics Inc. (United States); Robert L. Wade, U.S. Army Armament Research, Development and Engineering Ctr. (United States); Vince Matriciano, U.S. Army Program Executive Office Ammunition (United States); Jon Whetten, R. Scott Hartley, 5D Robotics Inc. (United States)

This paper provides details regarding a recent study with a group of four heterogeneous air and ground systems that collaborate using UWB RF tags as a means for shared positioning and accurate map building and digital marking. The system provides a significantly improved OPTEMPO by establishing a 3D position referenced environment.

Working under contract from the US Army, 5D led efforts to demonstrate a new approach to detection, marking and neutralization of land mines and IED hazards from October 27 – October 31, 2014 at Picatinny Arsenal, NJ and at November 2-7 at Camp LeJeune. 5D worked with a multiple small businesses including AerialMOB, Mesa, Freewave, Geophex, Segway, Bokam and Humanistic Robotics to create a multi-robot counter-IED system capable of detecting and digitally marking subsurface hazards within a correlated aerial image from a UAS.

The goal of the effort is to provide a significantly improved operational tempo by establishing a 3D position referenced environment which enables more accurate and efficient navigation, automated area coverage and marking. It also enables multiple vehicles to participate seamlessly in the same mission either simultaneously or in serial such that a second robot can return to a marked hazard to perform confirmation or neutralization. This UWB positioning uses tri-lateration of time of flight position readings to reliably navigate, perform digital marking and fuse multiple vehicle perspectives on the fly. One of the most important features is that the system is not dependent on GPS. A GPS jamming system was used at Camp LeJeune in tandem with the operation of the vehicles which shows the capability for GPS-denied operations. Another benefit of the demonstrated capability was fast-paced detection at 3mph and the ability for fully autonomous area scanning using the UWB to ensure full coverage and accurate digital marking.

Another key element of the solution is the development of accurate surveillance views and maps of the area of interest using low-cost camera equipped Quadrotor UAV which provides stealthy deployment of UWB tags which form the basis for the 3D position referenced environment. The paper discusses the result of a demonstration using low cost UAV flying through the area of interest at low altitude (about 50 feet). A UAV flies a pattern over the area of interest to provide a map to the control station which correlates with the position of the UWB tags. A map of the area is thus produced to within 5cm accuracy. To orchestrate the multiple UAS and UGV systems 5D uses a common operating picture based on shared positioning. Robots can then be deployed to the area and their movements coordinated and intelligently controlled with respect to the UWB tags and the referenced map.

The UWB constellation positioning also allows a second vehicle to come precisely to the same location (or the same robot to return with a different payload) for the purpose of confirmation or neutralization. In the Picatinny and Camp LeJeune experiments, the ACER returned to detected hazards in order to neutralize the detected hazard with a flail. The ACER accepts multiple neutralization payloads and can be controlled from a simple handheld wand. Use of a NQR or explosive sniffer could also be utilized as a means to discriminate explosives from clutter. Also, due to the accuracy of the map, it is now possible to compare and contrast multiple hazard mappings from day to day in order to identify changes (i.e. new hazards). This enables IED and land-mine detection even when there is significant clutter in the environment which would normally hinder advance rate.

At Camp Lejeune, 5D demonstrated an IEDD change detection capability that can work well even in areas with significant metal clutter. Especially within the MOUT facility at Camp LeJeune, the robot found many metal objects that were strewn throughout the area. Although it is possible to classify landmines to discriminate them from other metal targets, IEDs are more difficult to automatically classify because of the broad range of IED construction methods and components. To address this, a methodology for comparing IED scans from one day to another was developed. By using this means to tell what has changed in the ground the adverse effect of false positives is greatly reduced. The two images shown here allowed the user to easily see the new red blob indicating a buried hazard (encircled in black).

The level of position accuracy when coupled with the consistency of the detection algorithms provides a capability for change detection which is not possible without accurate before and after map alignment. The potential for vastly improved OPTEMPO and discrimination of false targets is through this combination of detection and positioning technologies.

9464-37, Session 9

YUV chrominance sub-sampling comparison using H.264

Andrew Thompson, Eric Balster, Univ. of Dayton (United States)

In this paper, a comparison of YUV 4:4:4, 4:2:2, and 4:2:0 video formats and their associated chrominance QP offset values is presented, using the H.264 standard. The goal of this paper is to determine the best video format for image quality versus image compression. This is a point of interest due to wireless video transmission quality and bandwidth limitations, which governs transmission rates over wireless communication systems.

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9465-1, Session 1

Imaging flash lidar for safe landing on solar system bodies and spacecraft rendezvous and docking

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NASA has been pursuing Flash lidar technology for autonomous, safe landing on solar system bodies and for automated rendezvous and docking. During the final stages of the landing from about 1 km to 500 m above the ground, the Flash lidar can generate 3-Dimensional images of the terrain to identify hazardous features such as craters, rocks, and steep slopes. The onboard flight computer can then use the 3-D map of terrain to guide the vehicle to a safe location. As an automated rendezvous and docking sensor, the Flash lidar can provide relative range, velocity, and bearing from an approaching spacecraft to another spacecraft or a space station. NASA Langley Research Center has developed and demsontrated a Flash lidar sensor system capable of generating 16k pixels range images with 7 cm precision, at 20 Hz frame rate, from a maximum slant range of 1800 m from the target area. This paper describes the lidar design and capabilities and presents the results of recent flight tests onboard a rocket-propelled free-flyer vehicle (Morpheus) built by NASA Johnson Space Center. The flights were conducted at a simulated lunar terrain site, consisting of realistic hazard features and designated landing areas, built at NASA Kennedy Space Center specifically for this demonstration test. This paper also provides an overview of the plan for continued advancement of the Flash lidar technology aimed at enhancing its performance while reducing its size and mass in compliance with constraints of space environment.

9465-2, Session 1

Improved resolution in time-of-flight measurement in a multi-pulse scanning-ladar system

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The resolution in time-of-flight (TOF) measurement in a scanning-LADAR system is typically limited by the rise time of the laser pulse used for illuminating the target. However, due to the timing jitter introduced by the signal processing electronics and pulse amplitude fluctuations, the object separations smaller than 20-30 cm cannot be accurately measured while using a laser pulse with close to 1ns risetime. In out scanning-LADAR system we use a time-to-amplitude converter (TAC) paired with two constant fraction discriminators (CFDs) to directly measure the TOF after each pixel is illuminated by a single laser pulse. Theoretically, this configuration is capable of resolving 10-15 cm separations. However, due to the above mentioned timing jitter, the resolution is degraded to about 20 cm for a single pulse measurement. In this presentation, I will discuss a technique that allows to overcome this obstacle. Implementing a multi-pulse pixel illumination technique, collecting the timing information by using a multichannel analyzer (MCA) and extracting the TOF data using a computer software can significantly improve the timing resolution of the scanning-LADAR system. This technique allows us to improve the resolution in TOF measurement in our system by up to 4 times.

9465-3, Session 1

Laser safety in design of near-infrared scanning lidars

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3D LIDARs with 1.5µm nanosecond pulse lasers have been increasingly used in different applications, the main reason for their popularity is that these LIDARs can be made to have high performance and at the same time can be made eye-safe. Because the laser hazard effect on eyes or skin at this wavelength region (>1.4µm) is mainly from the thermal effect accumulated from many individual pulses over a period of seconds, scanning can effectively reduce the laser beam hazard effect from the LIDARs.

Neptec LIDARs have been used in the docking application to the International Space Station, military helicopter landing and industrial mining applications. We have incorporated the laser safety requirement in the LIDAR design and conducted laser safety analysis for different operational scenarios. While 1.5µm is normally said to be the eye-safe wavelength, in reality a high performance 3D LIDAR needs high pulse energy, small beam size and high pulse repetition frequency (PRF) to achieve long range, high resolution and high density images. The resulting radiant exposure of its stationary beam could be many times higher than the limit for Class 1 laser device. Without carefully choosing laser parameters and scanning parameters including field-of-view, scan speed and pattern, a scanning LIDAR can't be eye- or skin-safe based only on its wavelength.

This paper discusses the laser safety considerations in the design of eye-safe scanning LIDARs, including laser pulse energy, PRF, beam size and scanning parameters in two basic designs of scanning mechanisms, i.e. galvanometer based scanner and Risley prism based scanner. The laser safety is discussed in terms of device classification, nominal ocular hazard distance (NOHD) and safety glasses' optical density (OD).

9465-5, Session 1

OEM fiber laser rangefinder for long-distance measurement

Alexandre Corman, Frédéric Chiquet, Thomas Avisse, SensUp (France); Marc Le Flohic, Keopsys SA (France)

Fiber lasers have already shown a wide field of use, in particular in remote sensing where it appeared relevant for LIDAR application. Since detection range and accuracy of measures are two of the main issue in laser range finding, the interest for that technology in telemetry became also relevant. In pulsed mode, fiber lasers allow huge energy storage (150µJ here, for a 10kW peak power) with a few kHz of repetition rate, against only several Hz at the same levels of energy for solid-state lasers. That combination enables our system to work in burst mode (typically 5kHz) on medium and long range (typically 15km, up to 20 – 25 km) and to average the distance values returned for each laser pulse: it thus increases significantly the measurement accuracy (<1m @ 3?). The laser source presents also a good beam quality at these levels of energy, a satisfying electro-optical efficiency (up to 20%) and an important reliability. But mostly, fiber sources can be adaptive, compact and so easily integrated in environments where the weight and the dimensions constraints are essential (System weight: 700g; Dimensions: 113 x 72 x 120 mm).

That is why our product is currently a very good balance in laser range

finding between range, accuracy and compactness, which makes it suitable for optronic integrators of the Defense and Security market.

9465-40, Session 1

Medium altitude airborne Geiger-mode mapping lidar system *(Invited Paper)*

William E. Clifton, Harris Corp. (United States)

No Abstract Available

9465-6, Session 2

Active and passive EO sensing for the detection of humans and handheld objects

Ove Steinvall, Håkan Larsson, Magnus Pettersson, Swedish Defence Research Agency (Sweden)

Some results from a low light trial are described. The purpose was to compare imaging performance for active and passive sensors in the visible, NIR and SWIR bands concerning detection and identification of humans carrying certain handheld objects and performing associated activities.

Both NIR and SWIR sensors provided passive imagery down to illumination levels between 1-10 lux corresponding to sunset-overcast to moonlight. The active mode gave usable imagery out to 3-4 km at much lower light levels. NIR and SWIR sensor images are compared concerning target to background contrast, cloth recognition and the detection of humans, activities and handheld objects. The target to background contrast was often somewhat better in the SWIR as compared with the NIR wavelength region. The contrast between different types of clothing was in general more discriminative in the NIR vs the SWIR. This was especially true for the active sensing modes. The recognition of large weapons could be done out to 600-1000 m range and handguns out to the 300-600 meter range. We found that activities could be detected and recognized out to 1400 m at least.

9465-7, Session 2

Anomaly detection in clutter using spectrally enhanced ladar

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Discrete return Laser Radar (Ladar) systems provide a series of echoes (first/last or multi-echo) that reflect from objects in a scene. On the other hand, Full-Waveform (FW)-Ladar systems measure the intensity of light reflected from objects continuously over a period of time. Research on FW-Ladar is relatively recent and has not been often applied to anomaly or target detection.

Recent work in Edinburgh has focussed on both large and small foot-print sensing using active multi-spectral Ladar (MSL) systems to retrieve structural and physiological properties of vegetation. In this work, we consider how Anomaly Detection (AD) and Automatic Target Recognition (ATR) scenarios can benefit from spectrally enhanced Ladar sensors in complex and cluttered environments, for example, the detection of targets hidden and camouflaged under dense foliage.

We present a probabilistic framework that allows the detection of anomalies in MSL data collected flying above an urban city or dense vegetation. We define clutter as data that is neither anomalous nor an object of interest. In the signal domain we define an anomaly as a full waveform time and spectral signature that does not conform to a prior expectation, defined using a learnt dictionary (subspace). We propose an online optimisation algorithm for dictionary learning based on stochastic approximations and augmenting our objective function with a discriminative term that represents the subspace separability properties. Formally, we define an anomaly as the change in the belief (dictionary vectors and signal representation coefficients) upon observing the new data measurement. We quantify the divergence by carrying out a hypothesis test (anomaly present/absent).

Our paper is divided into three sections. First, we present a multi-beam modeller for laser propagation through clutter which allows simulation of synthetic MSL data. The modeller allows flexible manageability of sensor characteristics, ambient light, 3D environment and the positioning of the sensor platform. We apply this synthesis to realistic 3D scenes with natural objects such as trees, and a 3D terrain with man-made objects (targets). Second, we study the backscattered Ladar returns over a wide range of wavelengths in the EM spectrum. Finally, we present a probabilistic cueing algorithm for dictionary learning which inheritably optimises the objective function for maximum inter-class variability. We then detect anomalies in a wide footprint MSL full waveform data, and hence focus on target detection and recognition in a more densely sampled MSL-derived point cloud, resulting in reduction in target search space and improving overall efficiency and reducing scan time.

9465-8, Session 2

Study of a dual mode SWIR active imaging system for direct imaging and non line of sight vision

Martin Laurenzis, Frank Christnacher, Institut Franco-Allemand de Recherches de Saint-Louis (France); Andreas Velten, Univ. of Wisconsin-Madison (United States) and Morgridge Institute for Research (United States)

The application of non line of sigh vision and see around a corner has been demonstrated in the recent past on laboratory level with round trip path lengths on the scale of 1 m as well as 10 m. This method uses a computational imaging approach to analyze the scattered information of objects which are hidden from the direct sensors field of view. Recent demonstrator systems were driven at laser wavelengths (800 nm and 532 nm) which are far from the eye-safe shortwave infrared (SWIR) wavelength band i.e. between 1.4 μm and 2 μm. Therefore, the application in public or inhabited areas is difficult with respect to international laser safety conventions.

In the present work, the authors evaluate the application of recent eye safe laser sources and sensor devices for non line of sight sensing and give predictions on range and resolution. Further, the realization of a dual mode concept is studied enabling both, the direct view on a scene and the indirect view on a hidden scene. While recent laser gated viewing sensors have high spatial resolution, their application in non line of sight imaging suffer from a too low temporal resolution due to minimal sensor gate width of around 150 ns. On the other hand, Geiger-mode single photon counting devices have high temporal resolution, but their spatial resolution is (until now) limited to array sizes of some thousand sensor elements. In this publication the authors present detailed theoretical and experimental evaluations.

9465-9, Session 2

High efficiency chirped Bragg gratings for stretching and compression of ultra short laser pulses at 800 nm

Vadim Smirnov, Leonid B. Glebov, Alexei L. Glebov, Oleksiy Mokhun, Larissa Glebova, Eugeniu Rotari, Ion Cohanoschi, Oleg Smolsky, OptiGrate Corp. (United States)

Chirped Bragg Gratings (CBGs) recorded in photo-thermo-refractive (PTR) glass have been successfully used as ultrashort pulse stretchers and compressors in Ultra Short Pulse Lasers (USPLs). Compared to traditional pairs of surface gratings, CBGs offer significant advantage in compactness

and robustness. In a single pass configuration, CBGs provide up to 100 nm spectral bandwidth, up to 500 ps of stretching time, and stretching rates from few ps/nm to > 500 ps/nm. It was shown that usage of a matched grating pair for stretching and compression results in a transform limited pulse durations. All above makes this technology preferable for manufacturing of industrial and military grade USPL systems. While efficiency of CBGs for wavelengths exceeding 1000 nm efficiency usually exceeded 90%, short wavelength CBGs operating in 800 nm range suffered with efficiency about 60%.

A technology of PTR glass based chirped gratings is based on holographic recording. It was found that efficiency of gratings designed for spectral region 700 1000 nm is deteriorated due to smeared interferometric patterns. In order to improve contrast of interference fringes, a new recording system has been developed. It resulted in significant enhancement of diffraction efficiency above 70%. We expect that improved efficiency at this spectral region will boost usage of CBGs for stretching and compression of high energy lasers such as Ti: Sapphire. Additionally, usage of gratings with large aperture would enable stretching and compressing of pulses with energy up to 10 mJ.

9465-10, Session 3

Atmospheric aerosol and molecular backscatter imaging effects on direct detection ladar

Douglas G. Youmans, Parsons Corp. (United States)

Multi-pulse waveforms are often used in laser radar systems to extend operational range by summing the multiple pulse returns and applying various summation + shifting algorithms. In addition to the usual lidar analysis procedures in the lidar literature, a ladar is usually tracking an object following a passive sensor “que,” producing a “slew” angular rotation rate. Generally a lead-angle is applied to the transmitted laser-mode for maximizing signal strength. Often a small “bi-static” separation of transmit aperture and receive aperture is employed. Furthermore, the last pulse of the pulse-train leaving the transmitter may be close to the receiving aperture when the first return pulse is expected, causing large backscatter “clutter” in the pixels of interest.

The imaging of a transmitted near-Gaussian laser-mode scattering off aerosols and molecules onto the focal plane, including these effects, will be analyzed. Methods for estimating the aerosol number density versus altitude and the volume backscatter coefficient of the aerosols will be discussed. The defocused backscatter images from the close pulses will be analyzed in a simple geometrical optics approximation.

9465-11, Session 3

All-fiber, compact, coherent wind lidar development for environmental monitoring applications

Narasimha S. Prasad, NASA Langley Research Ctr. (United States); Steven Vetorino, Allen J. Tracy, Rich Higgins, Russel Sibell, Sibelloptics, LLC (United States)

This paper describes an innovative, compact and eyesafe coherent lidar system developed for wind and wake vortex sensing applications. With all-fiber and modular architecture, the lidar system is configured to be compact and incorporates enhanced operational elegance and low power consumption features. The all-fiber architecture is built upon fiber seed laser coupled to uniquely configured fiber amplifier modules to provide ease of maintenance. The innovative features of lidar system, besides its all fiber architecture, include pulsewidth agility and 3D scanner unit. Operating at 1.5457 microns and with a PRF of up to 20 KHz, the lidar transmitter system with dimensions of 30” x 46” x60” is designed as a Class 1 system. With an operational range exceeding 10 km, the lidar is designed to measure wind velocities greater than 120 m/s, provide velocity accuracy of +/- 0.2 m/s and allow range resolution of lesser than 15 m. The dynamical configuration of pulsewidths from 50 ns to 400 ns allows high resolution wake vortex measurements. The lidar is integrated with a unique, user programmable hemispherical scanner unit. The scanner uses innovative liquid metal slip ring and is built using 3D printer technology with light weight nylon. As such, it provides continuous 360 degree azimuth and 180 degree elevation scan angles with an incremental motion of 0.001 degree. The lidar system is air cooled and requires 110 V for its operation. This compact and modular system is anticipated to provide mobility, reliability, and ease of field deployment for wind and wake vortex measurements. Currently, this wind lidar is undergoing validation tests under various meteorological conditions. Results of measurements involving wind characteristics that were recently carried out in Colorado will be presented.

9465-13, Session 4

Dynamic voxel modeling resolution based on quality assessments from lidar path tracing

Shea Hagstrom, Joshua B. Broadwater, Johns Hopkins Univ. Applied Physics Lab., LLC (United States)

Airborne LIDAR instruments are capable of delivering high density point clouds that can resolve sub-meter details. LIDAR sampling is inherently uneven in both 2D and 3D space, due to collection patterns as well as effects like occlusion. Taking full advantage of the detail available when creating 3D models therefore requires that resolution be adaptable to the amount of localized data. Voxel-based modeling of LIDAR has proven advantageous in many situations, but the traditional use of a fixed grid size prevents full realization of the potential resolution. By allowing the voxel size to vary across the model using spatial subdivision techniques this limitation can be overcome. An important part of this process is defining an appropriate limit of resolution for different sections of a model, and we incorporate information gained through tracing of LIDAR pulses to guide this decision process. Real-world data are used to demonstrate our results, and we show how dynamic resolution voxelization compares to using a fixed voxel size.

9465-14, Session 4

Agile-beam laser radar using computational imaging for robotic perception

Michael A. Powers, General Dynamics Robotic Systems (United States); Barry L. Stann, Mark M. Giza, U.S. Army Research Lab. (United States)

Our paper introduces a new concept that applies computational imaging techniques to laser radar for robotic perception. We observe that nearly all contemporary laser radars for robotic (i.e., autonomous) applications use pixel basis scanning where there is a one-to-one correspondence between world coordinates and the measurements directly produced by the instrument. In such systems this is accomplished through beam scanning and/or the imaging properties of focal-plane optics. While these pixel-basis measurements yield point clouds suitable for straightforward human interpretation, the purpose of robotic perception is the extraction of meaningful features from a scene, making human interpretability and its attendant constraints mostly unnecessary. The imposing size, weight, power and cost of contemporary systems is problematic, and relief from factors that increase these metrics is important to the practicality of robotic systems.

We present a system concept free from pixel basis sampling constraints that promotes efficient and adaptable sensing modes. The cornerstone of our approach is agile and arbitrary beam formation that, when combined with a generalized mathematical framework for imaging, is suited to the particular challenges and opportunities of robotic perception systems. Our hardware concept looks toward future systems with optical device technology closely

resembling modern electronically-scanned-array radar that may be years away from practicality.

We present the design concept and results from a prototype system constructed and tested in a laboratory environment using a combination of developed hardware and surrogate devices for beam formation. The technological status and prognosis for key components in the system is discussed.

9465-15, Session 4

Low-SWaP coincidence processing for Geiger-mode lidar video

Steven E. Schultz, Noel P. Cervino, Zachary D. Kurtz, Myron Z. Brown, Johns Hopkins Univ. (United States)

Photon-counting Geiger-mode lidar detector arrays provide a promising approach for producing three-dimensional (3D) video at full motion video (FMV) data rates, resolution, and image size from long ranges. However, coincidence processing required to filter raw photon counts is computationally expensive, generally requiring significant size, weight, and power (SWaP) and also time. In this paper, we describe a laboratory testbed developed to assess the feasibility of low-SWaP, real-time processing for 3D FMV based on Geiger-mode lidar. First, we examine a design based on field programmable gate arrays (FPGA) and demonstrate proof-of-concept results. Then we examine a design based on a first-of-its-kind embedded graphical processing unit (GPU) and compare performance with the FPGA. Results indicate feasibility of real-time Geiger-mode lidar processing for 3D FMV and also suggest utility for real-time onboard processing for mapping lidar systems.

9465-16, Session 4

Real-time on-board airborne demonstration of high-speed on-board data processing for science instruments (HOPS)

Jeffrey Y. Beyon, Tak-Kwong Ng, Mitchell J. Davis, James K. Adams, Stephen C. Bowen, James J. Fay, Mark A. Hutchinson, NASA Langley Research Ctr. (United States)

The project called High-Speed On-Board Data Processing for Science Instruments (HOPS) has been funded by NASA Earth Science Technology Office (ESTO) Advanced Information Systems Technology (AIST) program since April, 2012. The HOPS team recently completed two flight campaigns during the summer of 2014 on two different aircrafts with two different science instruments. The first flight campaign was in July, 2014 based at NASA Langley Research Center (LaRC) in Hampton, VA on the NASA's HU-25 aircraft. The science instrument that flew with HOPS was Active Sensing of CO2 Emissions over Nights, Days, and Seasons (ASCENDS) CarbonHawk Experiment Simulator (ACES) funded by NASA's Instrument Incubator Program (IIP). The second campaign was in August, 2014 based at NASA Armstrong Flight Research Center (AFRC) in Palmdale, CA on the NASA's DC-8 aircraft. HOPS flew with the Multifunctional Fiber Laser Lidar (MFLL) instrument developed by Excelis Inc. The goal of the campaigns was to perform an end-to-end demonstration of the capabilities of the HOPS prototype system while running the most computationally intensive part of the ASCENDS algorithm real-time on-board. The comparison of the two flight campaigns and the results of the functionality tests of the HOPS prototype system are presented in this paper.

9465-18, Session 5

Textured digital elevation model formation from low-cost UAV ladar/digital image data

Taylor C. Bybee, Scott E. Budge, Utah State Univ. (United States)

Textured digital elevation models (TDEMs) have valuable use in precision agriculture, situational awareness, and disaster response. However, scientific-quality models are expensive to obtain using conventional aircraft-based methods. The cost of creating an accurate textured terrain model can be reduced by using a low-cost (<$20k) UAV system fitted with LADAR and electro-optical (EO) sensors.

A texel camera fuses calibrated LADAR and EO data upon simultaneous capture, creating a texel image. This eliminates the problem of fusing the data in a post-processing step and enables both 2D- and 3D-image registration techniques to be used. This paper describes formation of TDEMs using simulated data from a small UAV gathering swaths of texel images of the terrain below. Being a low-cost UAV, only a coarse knowledge of position and attitude is known, and thus both 2D- and 3D-image registration techniques must be used to register adjacent swaths of texel imagery to create a TDEM.

The process of creating an aggregate texel image (a TDEM) from many smaller texel image swaths is described. The algorithm is seeded with the rough estimate of position and attitude of each capture. Details such as the required amount of texel image overlap, registration models, simulated flight patterns (level and turbulent), and texture image formation are presented. In addition, examples of such TDEMs are shown and analyzed for accuracy.

9465-19, Session 5

Visualization of 3D images from multiple texel images created from fused lidar/digital imagery

Cody Killpack, Scott E. Budge, Utah State Univ. (United States)

The ability to create 3D models using registered texel images (fused ladar and digital imagery), is an invaluable tool for disaster management, situational awareness, and even automatic target recognition (ATR). These models are automatically generated by transforming multiple texel images into a single common reference frame. However, rendering a sequence of independently registered texel images often presents challenges due to the problems caused by sensor noise and stretched triangles resulting from and data acquired from different perspectives.

As a result of these defects, standard rendering techniques are not suitable for texturing 3D texel models. Although accurately registered, the textures are often incorrectly overlapped and interwoven. Forming a texture atlas (stitching images together) is impractical, due to the independent nature of the underlying data sets. Consequently, corrections must be done after all the textures have been rendered, by determining the best texture for any given area of the model. The procedures for computing and ranking these textures (via geometric 'confidence' measures), are done in real-time. The visual defects of a model are reduced when overlapping textures are hidden, exposed, or blended by using the view-dependent algorithm presented in this paper. Successful rendering examples, including those that use both synthetic and real-world data sets, are presented.

9465-20, Session 5

Modeling individual trees in an urban environment using dense discrete return LiDAR

Madhurima Bandyopadhyay, Jan A. N. van Aardt, Martin van Leeuwen, Rochester Institute of Technology (United States)

The urban forest is becoming increasingly important in the contexts of urban green space, carbon sequestration and offsets, and socio-economic impacts. This has led to a recent increase in attention being paid to urban environmental management. Tree biomass, specifically, is a vital indicator of carbon storage and has a direct impact on urban forest health and carbon sequestration. Remote sensing has been used extensively in measuring dynamics of vegetation and estimating biomass. Light detection and ranging (LiDAR) has proven useful to characterization of the three dimensional (3D) structure of forests. In urban contexts however, information is frequently required at the individual tree level, necessitating the proper delineation of tree crowns. Yet, crown delineation is challenging especially for urban trees where a wide range of stress factors and cultural influences affect growth. In this paper high resolution LiDAR data are used to infer biomass based on individual tree attributes. First, a crown height model (CHM), derived from LiDAR point clouds, is used to determine the crown boundaries using a minimum-valley-following approach. Next, a best-fitting circle approach, with circles falling inside the crown boundaries, is used to detect the individual trees by fitting geometric crown shapes. Finally, individual tree attributes are used to estimate tree biomass and the results are validated with associated field mensuration data. Initial results show that detection of individual trees from mixed tree stands is over 80% accurate, and the estimated tree attributes are in agreement with the truth data. We wish to expand our test area to ensure the robustness of this method. Final results will be presented at the conference.

9465-21, Session 5

Simulation of lidar propagation through a tree canopy in 3D

Angela M. Kim, Richard C. Olsen, Naval Postgraduate School (United States); Martin Béland, Univ. Laval (Canada)

A Monte Carlo ray tracing simulation of LiDAR propagation has been expanded to 3 dimensions, and makes use of the high-fidelity tree voxel model VoxLAD for realistic simulation of a single tree canopy. The VoxLAD model uses terrestrial LiDAR scanner data to determine the Leaf Area Density (LAD) measurements for small volume voxels (~100 cm^3), and provides a definition of the statistical distribution of leaves within each voxel. Within the LiDAR propagation model, LiDAR energy may be absorbed, transmitted or reflected. Information from the VoxLAD model is used to determine the probability of simulated LiDAR energy interacting with materials at the voxel location, and the directional scattering should an interaction occur. The high spatial fidelity of the VoxLAD models enables simulation of small-footprint LiDAR systems. Results are presented demonstrating the full-waveform simulation capability of the model, and highlight potential challenges and opportunities of small-footprint waveform LiDAR data.

9465-22, Session 5

Comparison of full-waveform, photon counting and discrete analog lidar data

Scott C. Runyon, Angela M. Kim, Jeremy P. Metcalf, Richard C. Olsen, Naval Postgraduate School (United States)

Full-waveform LiDAR data from an AHAB Chiroptera system with a 515 nm and 1032 nm laser (~6 pts per m^2), photon counting data from the Sigma Space HRQLS system with a 532 nm laser (~17 pts per m^2), and discrete analog data from and Optech Orion C200 system (~60 pts per m^2) were collected from aerial platforms over Monterey, CA, USA in fall 2012 and fall 2013. The study area contains residential neighborhoods, forested regions, inland lakes, and Pacific Ocean near-shore environment. Significant ground truth in the form of GPS measurements and terrestrial LiDAR scans enable the LiDAR data to be compared in terms of precision, accuracy, point cloud density, and degree of tree canopy penetration.

9465-23, Session 5

Exploitation of multi-wavelength lidar for terrain classification and foliage penetration

Richard C. Olsen, Naval Postgraduate School (United States); Chelsea H. Esterline, Naval Postgraduate School (Chile); Angela M. Kim, Jeremy P. Metcalf, Naval Postgraduate School (United States)

Full-waveform LiDAR data from an AHAB Chiroptera system with a 515 nm and a 1032 nm laser,were collected from an aerial platform over Monterey, CA, USA in Spring 2014. Data were acquired at 5-6 pts/m2. The study area contains residential neighborhoods, forested regions, inland lakes, and Pacific Ocean near-shore environment. Data analysis on the two-color data are shown here for discrete return and waveform data for purposes of foliage penetration and target detection. Spectral analysis techniques are applied for terrain classification, and distinctions in the ability of the two wavelengths to penetrate foliage. Validation of the results are via coincident airborne (spectral imaging) data, satellite imaging data, and in-situ measurements. Time permitting, comparison will be made to results from high-point density airborne data from the Optech system (C-200), at point densities of 30-60 pts/m2.

Conference 9465B: Atmospheric Propagation XII

Thursday 23–23 April 2015

Part of Proceedings of SPIE Vol. 9465 Laser Radar Technology and Applications XX; and Atmospheric Propagation XII

9465-24, Session 6

An updated look at tilt-removed beam propagation in the atmosphere

Gary Baker, Lockheed Martin Space Systems Co. (United States)

No Abstract Available

9465-25, Session 6

Wavefront sensing and phase reconstruction with multi-aperture Zernike filter

Mikhail A. Vorontsov, Univ. of Dayton (United States) and Optonicus (United States); Svetlana L. Lachinova, Mathieu Aubailly, Optonicus (United States); Behzad Bordbar, Univ. of Dayton (United States)

A novel wavefront sensor that is composed of a densely packed array of phase-contrast Zernike filters, referred to as the multi-aperture Zernike (MAZ) sensor, and iterative techniques for phase retrieval from the MAZ sensor are proposed and analyzed through wave-optics numerical simulations. It is shown that the MAZ sensor can provide accurate reconstruction of phase of optical fields with strongly nonuniform intensity distribution. Due to parallel nature of optical field processing by the MAZ sensor, retrieval of phase requires a relatively small number of iterations and can be performed using parallel computations. The proposed MAZ sensor can be used in wide range of applications including atmospheric and eye aberration sensing, adaptive optics, optical metrology, and phase-contrast microscopy.

9465-26, Session 6

Optical turbulence with anisotropy at different scales and its effect on laser beam propagation along vertical paths

Italo Toselli, Olga Korotkova, Univ. of Miami (United States)

Atmospheric turbulence can be anisotropic above the boundary layer because a layered structure of eddies is often present. Also, the degree of anisotropy is higher near the outer scale but it vanishes at small scales where eddies are essentially isotropic. In this paper, we use a non-Kolmogorov power spectrum with an effective anisotropic parameter to include the effect of anisotropy at different scales. By using the spectrum, we theoretically analyze the effect of anisotropy on turbulence parameters such as long-term beam spread and scintillation for laser beams propagating along vertical paths. Although our results are valid only for the case of anisotropy along the direction of propagation, they are of interest for applications such as astronomy, vertical directed energy and vertical laser communications links.

9465-27, Session 6

Scientific data analysis of atmospheric turbulence through distributed computing

Sara B. Belichki, Christopher A. Smith, Joseph T. Coffaro, Michael G. Panich, Ronald L. Phillips, Larry C. Andrews, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Using theory to mathematically model the atmospheric turbulence phenomenon occurring in laser propagation, empirical data is a requirement for the validation of such theory in the scientific community. Meteorological and atmospheric data is essential toward the characterization of beam propagation through turbulence. Modern technological advancements have brought forth diverse means of aggregating vast amounts of data through various instrumentation such as sensors and detectors. However, the processing of such sizable data proves difficult in terms of computational throughput and efficiency alongside with the development of proper algorithms to learn patterns and correlations existing within the data. With these current obstacles considered, this paper seeks to develop and assess distributed computing architectures and machine learning algorithms that can provide validation and understanding of turbulence for such applications. By implementing classification and regression algorithms, it is hypothesized that the behavior of the beam itself may be categorized and possibly predicted or correlated with meteorological parameter-based values. Classification algorithms such as cluster analysis are examined to categorize parameters such as Cn2 and the scintillation index into groups that correlate with anisotropic and non-homogeneous atmospheric conditions. Regression algorithms such as logistic regression are investigated to provide a predictive means toward quantifying atmospheric conditions and its affect on the laser beam through cost function analysis. Lastly, feature set extraction will be taken from laser image data to develop features that better classify turbulent beam behavior. Correlations with beam spot size, scintillation index, inner scale, and propagation distance will be examined from the resulting feature set.

9465-28, Session 7

A low cost, low power, S-band radar for atmospheric turbulence studies

Thomas C. Farrell, Air Force Research Lab. (United States)

We present a frequency modulated continuous wave radar capable of measuring atmospheric turbulence profiles within the Earth's surface layer. Due to the low cost and easily automated design, a number of units may be built and deployed to sites of interest around the world. Each unit would be capable of collecting turbulence strength, as a function of altitude, with a range of up to 50 meters above ground level. Such data is valuable to developers of directed energy, lasercom, imaging, and other optical systems, where good engineering design is based on an understanding of the details of the turbulence in which those systems will have to operate.

The radar is based on the design described in [1]. It is FCC compliant, operating in the 2.4 GHz instrumentation, science, and medical (ISM) band with less than 1 watt effective isotropic radiated power. It is expected to cost less than $1000 per unit and is built from commercial off the shelf parts, along with easily constructed horn antennas. Major modifications to the design in [1] are the inclusion of horn antennas for directivity, and a straight forward processing software change that increases integration times to the order of tens of seconds to a minute.

Here, the prototype system is described and preliminary data is presented.

[1] Charvat, Gregory, Jonathan Williams, Alan Fenn, Steve Kogon, and Jeffrey Herd. RES.LL-003 Build a Small Radar System Capable of Sensing Range, Doppler, and Synthetic Aperture Radar Imaging, January IAP 2011. (MIT OpenCourseWare: Massachusetts Institute of Technology), http://ocw.mit.edu/resources/res-ll-003-build-a-small-radar-system-capable-of-sensing-range-doppler-and-synthetic-aperture-radar-imaging-january-iap-2011

9465-29, Session 7

Estimation of the path averaged atmospheric refractive index structure constant from time-lapse imagery

Santasri Basu, Jack E. McCrae, Air Force Institute of Technology (United States) and Oak Ridge Institute for Science & Education (United States); Steven T. Fiorino, Air Force Institute of Technology (United States)

The sea level vertical refractive index gradient in the US Standard Atmosphere Model is 2.7 x 10-8 m-1. At any particular location, the actual refractive index gradient deviates from this value due to turbulence and also depending upon local conditions and time of day. An imaging experiment has been conducted to measure the variability of this gradient over time. A tripod-mounted digital camera focused on a building 8 miles away takes images every minute. Changes in the refractive index gradient along the path result in position shifts between images. The camera and the building are at nearly the same elevation; hence the path through turbulence is nearly horizontal. Shifts between the images are computed using correlation techniques. This experiment attempts to separate two factors causing shifts between images: atmospheric turbulence which can be expected to cause the images to wander randomly, quickly, and isotropically; plus a non-turbulent component where changes to the average refractive index gradient along the path are expected to cause the images to move vertically, more slowly, and perhaps in correlation with the solar heating and other weather conditions. To isolate the camera from base disturbances, the camera and data collection system are in a ground floor temperature controlled laboratory looking out through a window. While interference from base disturbances hasn't yet been ruled out, initial results indicate the path-averaged refractive index gradient often makes excursions as large as its mean standard value. The results from the experiment show good agreement with numerical weather data.

9465-30, Session 7

Increasing persistence through scattering environments by using circularly polarized light

John D. van der Laan, College of Optical Sciences, The Univ. of Arizona (United States) and Sandia National Labs. (United States); David A. Scrymgeour, Jeremy B. Wright, 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 circularly polarized light persists through scattering environments better than linearly polarized light. Circularly polarized light can therefore be utilized to increase range and contrast in these scattering environments. Specifically, we show persistence is enhanced by up to a factor of four for circularly polarized light in scattering environments of monodisperse polystyrene microspheres in water, modeling fog and clouds. Experimental and simulation results are generated for the scattering environments of monodisperse polystyrene microspheres with particle diameters of 0.1, 1.0, 2.0, and 3.0 microns and varying optical thicknesses. These particle sizes represent size parameters which correspond to marine and continental fog particle sizes for infrared wavelengths. Monte Carlo simulations predict a larger persistence benefit for circular polarization versus linear polarization compared to experimental results through an entire hemisphere. We show that angular collection limitations, in both experiments and simulations, must be taken into account to accurately quantify circular polarization's persistence benefits in scattering environments. With angular correction, circular polarization persistence is still better than that of linear polarization, but this persistence benefit is not as large as those for full-hemispherical simulations.

9465-31, Session 7

Scintillation effects of double-pass optical beams in atmospheric turbulence

Joseph T. Coffaro, Michael G. Panich, Univ. of Central Florida (United States); Sara B. Belichki, Christopher A. Smith, Ronald L. Phillips, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); Larry C. Andrews, Univ. of Central Florida (United States)

The purpose of this research is to investigate scintillation fluctuations resulting from a collimated laser beam at the target and in the pupil plane of the reflected optical beam during double-pass atmospheric propagation. This paper examines the effects of scintillation on an optical beam that is reflected back along the same outgoing optical path. The scintillation effects are obtained on the beams reflected back from two targets: a retro-reflector and a rough surface over a propagation distance of 1km. It is from the examination of scintillation effects that this research explores characterizing the change in strength of atmospheric turbulence at the target and in the pupil plane of the reflected beam through propagation along a reciprocal path.

9465-32, Session 7

The spectral transparency of the surface layer marine and coastal atmosphere

Gennady A. Kaloshin, V.E. Zuev Institute of Atmospheric Optics (Russian Federation)

We present the results of numerical modeling of the spectral transparency of the surface layer marine and coastal atmospheric aerosols, which are based on the microphysical model Marine Aerosol Extinction Profiles (MaexPro). The model is created on long-term observations of size distributions for 0.01–100 ?m particles. The fundamental feature of the model is a parameterization of amplitudes and widths for aerosol modes of the aerosol size distribution function (ASDF) as functions of fetch and wind speed. The shape of the ASDF and its dependence on meteorological parameters, altitudes above the sea level (H), fetch (X), wind speed (U), and relative humidity is investigated. The model is primarily to characterize aerosols for the near-surface layer (within 25 m). The model is also applicable to higher altitudes within the atmospheric boundary layer, where the change in the vertical profile of aerosol is not very large. In this case, it is only valid for "clean" marine environments, in the absence of air pollution or any other major sources of continental aerosols, such desert dust or smoke from biomass burning. The spectral profiles of the aerosol extinction coefficients calculated by MaexPro are in good agreement with observational data and the numerical results obtained by the well-known Navy Aerosol Model and Advanced Navy Aerosol Model codes. Moreover, MaexPro was found to be an accurate and reliable instrument for investigation of the atmospheric aerosols transparence.

9465-33, Session 8

Low-SWAP lasercomm terminal architecture for high-bandwidth communications under highly scintillated links

Juan C. Juarez, Radha Venkat, Ryan P. DiNello-Fass, David M. Brown, Hala Tomey, Johns Hopkins Univ. Applied Physics Lab., LLC (United States)

No Abstract Available

9465-34, Session 8

Lasercomm beacon architecture for link acquisition in highly scintillated environments

Radha Venkat, Juan C. Juarez, Johns Hopkins Univ. Applied Physics Lab., LLC (United States)

No Abstract Available

9465-35, Session 8

Demonstrating capacity-approaching FSO communications

Thomas R. Halford, Michael P. Fitz, Cenk Kose, Jonathan Cromwell, Steven Gordon, TrellisWare Technologies, Inc. (United States)

No Abstract Available

9465-36, Session 8

The ONR high-bandwith Lasercom project update

Linda M. Thomas, Christopher I. Moore, William S. Rabinovich, U.S. Naval Research Lab. (United States)

No Abstract Available

9465-37, Session 8

The ONR high-bandwidth lasercom project: analysis of propagation data

William S. Rabinovich, Christopher I. Moore, Linda M. Thomas, U.S. Naval Research Lab. (United States)

No Abstract Available

9465-39, Session 8

Mid-IR free-space optical communication with quantum cascade lasers

Edward Luzhansky, NASA Goddard Space Flight Ctr. (United States) and Univ. of Maryland Baltimore County (United States); Fow-Sen Choa, Univ. of Maryland, Baltimore County (United States); Scott Merritt, Anthony W. Yu, Michael A. Krainak, NASA Goddard Space Flight Ctr. (United States)

Free space optical communication link with simulated atmospheric turbulence investigation using un-cooled system. Pulsed Quantum Cascade Laser was used as transmitter and photoelectromagnetic detector as receiver. For high photon efficiency and to eliminate QCL thermal effects signal was modulated at 32-ary Pulse Position Modulation (PPM) scheme. Concept enables extremely small and atmospheric propagation efficient optical communication system.

9465-38, Session PSThu

The effect of the aero-optic's additional focal length on the airborne platform laser communication optical system

Yuan Hu, Changchun Univ. of Science and Technology (China) and Beijing Institute of Technology (China); Tianyuan Gao, Changchun Univ. of Science and Technology (China); Dewen Cheng, Beijing Institute of Technology (China); Shoufeng Tong, Huilin Jiang, Changchun Univ. of Science and Technology (China)

The aero optics effects caused by high speed flight may have a serious impact on the performance of space laser communication systems. In the field of space laser communication technology engineering and its practical application, this is a research problem that is highly significant. For the complex flow field that is generated by the interaction between the aircraft surface and air, the aero optics effects are usually divided into two parts, namely, laminar flow and turbulent flow. This paper discusses the principle of how the aero optics effect causes the image of the space laser communication optical system to blur and leads to a dispersed spot. The research focuses on the additional focal length (AFL) effect caused by the laminar flow field, a simulation analysis of the relationship between the flight altitude, speed, window shape and the system performance, and provides solutions to the defocus phenomenon that has been observed in airborne tests. Finally it is hoped that the paper can provide a solution that effectively compensates for the AFL effect on laser communication optical systems, and improves the communication between aircrafts.

Conference 9466: Laser Technology for Defense and Security XI

Tuesday - Wednesday 21–22 April 2015

Part of Proceedings of SPIE Vol. 9466 Laser Technology for Defense and Security XI

9466-1, Session 1

Ring cavity surface emitting quantum cascade laser with a near Gaussian beam profile

Pedro N. Figueiredo, Robert E. Peale, Andrey V. Muraviev, Univ. of Central Florida (United States)

We propose a vertical spiral phase corrector for ring cavity surface emitting (RCSE) QCLs. This will enable a near-Gaussian generated beam profile. A problem with usual RCSE QCLs is their donut-shaped intensity distribution with a node along the symmetry axis of the ring. This arises because of the 180 deg phase difference for the azimuthally polarized rays emitted from opposite elements of the ring. We theoretically demonstrate that near-Gaussian beams can be achieved with the proposed spiral phase corrector, which adds one wavelength of additional optical path in going once around the ring. Various three dimensional lithographic techniques for fabricating such a phase shifter, including a grey scale mask, electron-beam resist dose dependency, and two photon induced photopolymerization are considered. RCSE QCLs with the proposed phase corrector will feature better beam quality, higher intensity, and better resistance to optical damage than traditional edge- emitting QCLs.

9466-2, Session 1

Continuous-wave deep ultraviolet sources for resonance Raman explosive sensing

Balakishore Yellampalle, Robert B. Martin, Mikhail Sluch, Robert V. Ice, William B. McCormick, Brian E. Lemoff, West Virginia High Technology Consortium Foundation (United States)

A promising approach to stand-off detection of explosive traces is using resonance Raman spectroscopy with Deep-ultraviolet (DUV) light. The DUV region offers two main advantages: strong explosive signatures due to resonant and λ-4 enhancement of Raman cross-section, and lack of fluorescence and solar background. For DUV Raman spectroscopy, continuous-wave (CW) or quasi-CW lasers are preferable to high peak powered pulsed lasers because Raman saturation phenomena and sample damage can be avoided. In this work we present a very compact DUV source that produces greater than 1 mw of CW optical power. The source has high optical-to-optical conversion efficiency, greater than 5 %, as it is based on second harmonic generation (SHG) of a blue/green laser source using a nonlinear crystal placed in an external resonant enhancement cavity. The laser system is extremely compact, lightweight, and can be battery powered. Using two such sources, one each at 236.5 nm and 257.5 nm, we are building a second generation explosive detection system called Dual-Excitation-Wavelength Resonance-Raman Detector (DEWRRED-II). The DEWRRED-II system also includes a compact dual-band high throughput DUV spectrometer, and a highly-sensitive detection algorithm. The DEWRRED technique exploits the DUV excitation wavelength dependence of Raman signal strength, arising from complex interplay of resonant enhancement, self-absorption and laser penetration depth. We show sensor measurements from explosives/precursor materials at different standoff distances.

9466-3, Session 1

AlGaInN laser diode technology and systems for defence and security applications

Stephen P. Najda, Piotr Perlin, Tadek Suski, Lucja Marona, Mike Bockowski, Mike Leszczynski, Przemek Wisniewski, Robert Czernecki, TopGaN Ltd. (Poland); Robert Kucharski, Ammono S.A. (Poland); George Tagowski, TopGaN Ltd. (Poland); Scott Watson, Antony Kelly, Univ. of Glasgow (United Kingdom)

The latest developments in AlGaInN laser diode technology are reviewed for defence and security applications such as display and underwater communications. The AlGaInN material system allows for laser diodes to be fabricated over a very wide range of wavelengths from u.v., ~380nm, to the visible ~530nm, by tuning the indium content of the laser GaInN quantum well. Advantages of using Plasma assisted MBE (PAMBE) compared to more conventional MOCVD epitaxy to grow AlGaInN laser structures are highlighted. Ridge waveguide laser diode structures are fabricated to achieve single mode operation with optical powers of >100mW in the 400-420nm wavelength range with high reliability. Visible light communications at high frequency (up to 2.5 Gbit/s) using a directly modulated 422nm Gallium-nitride (GaN) blue laser diode is reported.

High power operation of AlGaInN laser diodes is also reviewed. We demonstrate the operation of a single chip, high power AlGaInN laser diode 'mini-array' consisting of a 3 stripe common p-contact configuration at powers up to 2.5W cw in the 408-412 nm wavelength range. Low defectivity and highly uniform GaN substrates allow arrays and bars of nitride lasers to be fabricated. Laser bars of up to 5mm with 20 emitters have shown optical powers up to 4W cw at ~410nm with a common contact configuration. An alternative package configuration for AlGaInN laser arrays allows for each individual laser to be individually addressable allowing complex free-space and/or fibre optic system integration within a very small form-factor. TopGaN are developing a new range of high power laser array technology over the u.v.- visible spectrum together with new packaging solutions for optical integration.

9466-4, Session 1

Recent progress in high-power ultrafast thulium-doped fiber lasers and mid-infrared supercontinuum sources

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The research on high-power fiber lasers has attracted worldwide attentions because of their essential characteristics such as excellent beam quality, convenient heat management and compact configuration, which are considered as the next generation laser source for industrial, medical, and military application field. The research on high-power ultrafast thulium-doped fiber lasers at 2 μm wavelength and mid-infrared (mid-IR) supercontinuum sources at 2~5 μm wavelength is one of these hot spots because of their potential applications in eye-safe radar, material processing, and electro-optical countermeasure system, which has a irreplaceable role compared to other wavelength fiber lasers. Here, we will review the research work of our group at 2 μm high-power ultrafast thulium-doped fiber lasers and 2~5 μm high-power mid-IR supercontinuum sources. Firstly, we will introduce a high-power picosecond-pulsed thulium-doped all-fiber MOPA, the amplifier yielded 120 W of average output power at central wavelength

of 1963 nm with pulse duration of 16 ps. And then, we will introduce a high-power single-frequency, single-polarization, thulium-doped all-fiber MOPA system by using all-PM thulium-doped fiber and all-PM-fiber components. The MOPA yielded 210 W of single-frequency, linear-polarized laser output at central wavelength of 2000.9 nm with a polarization extinction ratio of >17 dB. Finally, we will introduce a high-power mid-IR supercontinuum generation with up to 24.3 W average power and spectrum spanning from 1.9 to beyond 3.8 μm in a single-mode ZBLAN fiber pumped by a 2 μm amplified picosecond pulses from a single-mode thulium-doped fiber MOPA.

9466-5, Session 2

High temperature operating diode laser pumps for directed energy fiber lasers

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Kilowatt-class fiber lasers and amplifiers are becoming increasingly important building blocks for power-scaling laser systems in various different architectures for directed energy applications. Currently, state-of-the-art Yb-doped fiber lasers operating near 1060 nm operate with optical-to-optical power-conversion efficiency of about 66%. State-of-the-art fiber-coupled pump diodes near 975 nm operate with about 50% electrical-to-fiber-coupled optical power conversion efficiency at 25C heatsink temperature. Therefore, the total system electrical-to-optical power conversion efficiency is about 33%. As a result, a 50-kW fiber laser will generate 75 kW of heat at the pump module and 25 kW at the fiber laser module with a total waste heat of 100 kW. It is evident that three times as much waste heat is generated at the pump module. While improving the efficiency of the diodes primarily reduces the input power requirement, increasing the operating temperature primarily reduces the size and weight for thermal management systems. We will discuss improvement in diode laser design, thermal resistance of the package as well as improvement in fiber-coupled optical-to-optical efficiency to achieve high efficiency at higher operating temperature. All of these factors have a far-reaching implication in terms of significantly improving the overall SWAP requirements thus enabling DEW-class fiber lasers on airborne and other platforms.

9466-6, Session 2

Higher efficiency low weight, high-brightness fiber pump modules

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Great advancements in fiber laser technology have brought within reach the possibility of deployable directed energy systems. In all such systems there remains a high premium on high efficiency and low weight. Diode pump modules constitute a critical element of all fiber laser systems, and while improvements to pump diodes alone represent a direct benefit to directed energy systems, a more fruitful approach is to review engineering tradeoffs at the level of the whole fiber system. This paper reports on the outcome of such a systems review and improvement effort as concerns an existing, commercial kW class fiber amplifier. Data for next generation diode pump devices with yet further increased power-to-weight ratio will be presented.

DILAS has delivered in volume to the US defense community the IS46, a commercial pump diode with 300W of output power from a 200?m/0.22NA fiber-coupled module weighing in at ~300 grams. The unit provides the best weight-to-power ratio available while retaining excellent spatial and spectral brightness. In this paper, results on improvements to the IS46 are reported. Advances in power output, wall-plug efficiency, and further weight reduction will be detailed. The design approach leading to the operational enhancements will be discussed, to include a review of the system of which the IS46 is a part. Specific areas of technical investigation include: thermal resistance reduction through improved heatsink design, increased diode cavity length for reduction of slow-axis divergence, electrode design for the reduction or electrical resistance, and deployment of a volume holographic grating to improve spectral match between pump diode and fiber laser, and selection of optical components. Particular attention will be paid to the increase of diode cavity length and reduction of heatsink thermal resistance, as they are deemed to have particularly strong effects on the module performance, and are so connected through their fundamental effects on the module.

9466-7, Session 2

Resonantly pumped Kerr-lens mode-locked Er:YVO4 laser

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Orthovanadate crystals, such as YVO4, possess a high nonlinear refractive index which is an order of magnitude better than that of YAG. This large nonlinearity makes it possible to develop a relatively simple self-starting mode-locked laser. Here we report what is believed to be the first, resonantly (in-band) pumped, self-starting Er-doped YVO4 laser, based on the host crystal Kerr nonlinearity. An Er:YVO4 gain element was placed between the two plano-concave mirrors (both with 100 mm radius of curvature) in a 63 cm long, Z-shaped laser cavity with unequal shoulder lengths. The laser crystal was longitudinally end-pumped into one of the major absorption lines of Er:YVO4 at 1534 nm by a CW Er-doped fiber laser and the self-starting Kerr-lens mode-locking regime was successfully achieved. The laser operated at 1603 nm (p-polarization). With 18 W of incident pump power, picosecond pulses with a maximum energy of ~8 nJ were obtained at a pulse repetition rate of ~238 MHz.

9466-8, Session 2

DBR and DFB lasers in Nd and Yb doped photo-thermo-refractive glasses

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The need of environment insensitive, compact, robust, narrow line laser sources stimulated the development of hybrid devices such as distributed Bragg reflector (DBR) and distributed feedback (DFB) lasers. Recent development of photo-thermo-refractive (PTR) glass for recording volume holograms has led to the creation of high-efficiency low-loss volume Bragg gratings (VBGs). It was found that co-doping PTR glass with such rare earth luminescent ions (Yb and/or Nd) results in a complex material that combines both photosensitivity and high efficiency luminescence.

The first monolithic solid state DFB laser made in Yb-doped PTR glass with a volume Bragg grating occupying the whole volume was demonstrated. Operating in a single longitudinal mode regime it produces narrow linewidth (<250 kHz) with a power of up to 150 mW in forward and backward directions. The DBR laser based on Yb-doped PTR glass was developed by

recording 99% reflective VBGs on the ends of the active element. Both CW and pulsed regimes were investigated and the influence of thermal effect on beam quality was studied.

In case of Nd-doped PTR glass a DBR laser consisting of an external high reflecting conventional multilayer dielectric mirror and a reflecting VBG within a gain element as an output coupler.

9466-9, Session 3

High-power operation of Yb-doped fiber laser at 976 nm: present status and applications *(Invited Paper)*

Eric Cormier, Univ. Bordeaux 1 (France)

During the past years, we have developed a technology enabling high power operation of Yb-doped fiber lasers and amplifiers on the zero phonon line thus emitting around 976 nm. Efficient operation requires very specific fiber design and laser architectures. Different regimes have been investigated at this wavelength from continuous wave to femtosecond with tens of W output power and up to mJ energy in a diffraction limited beam. Power scalability will be discussed and major applications such as high-brightness optical pumping presented.

9466-10, Session 3

Advances in resonantly-pumped Tm-doped fiber amplifiers

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We recently demonstrated high efficiency lasing in Tm-doped fiber by using a resonant tandem pumping method. These results used core pumping and were limited to a conventional fiber oscillator configuration at <10W output power. In this paper, we discuss recent advancements in resonantly-pumped Tm-doped fiber amplifiers. We explore the effects of pump bleaching in these resonantly-pumped fibers and compare both core- and cladding-pumped amplifier configurations. By pumping a Tm-doped fiber amplifier with a Tm-doped fiber laser operating at 1908nm (in the tail of the absorption band) and lasing in the 2000nm spectral region, we have generated more than 123W of output power with >91% slope efficiency, 90% optical efficiency, and >18% electrical-to-optical efficiency . This is possible due to the low losses in the fiber as well as the high quantum efficiency of our pump to lasing wavelength. This high optical efficiency significantly reduces waste heating in the fiber, which has the potential to allow for power scaling of Tm-doped fiber amplifiers to the multi-kW power levels using conventional diode technology and without relying on diode brightness enhancements. We discuss our experimental amplifier results with both core-pumping and cladding-pumping; we review our numerical model which shows excellent agreement to the experimental results; and we use this model to explore the power scaling potential for the resonant tandem pumping approach.

9466-11, Session 3

Higher order mode selection for power scaling in laser resonators using transmitting 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 allowing multiple guided modes, decreasing beam quality. Selection of a pure transverse mode can improve the beam quality and brightness of the laser resonator. In particular, selection of pure higher order modes can allow for increased efficiency. Due to the known phase distribution, a pure higher order mode can be easily converted to a single lobe beam with high brightness. We propose a new method of transverse mode selection using volume Bragg gratings (VBG) as an angular filter aligned to provide maximum diffraction efficiency for higher order modes.

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 angular filtering in the near field, allowing for the design of compact spatial filters. Off axis alignment of the TBG allows for a single transverse mode to be diffracted with high efficiency, while other modes experience high losses.

Modeling on the effect of diffraction efficiency and laser efficiency in a laser resonator are presented. Experimental results of higher order mode selection using a ribbon fiber with core dimensions of 107.8?m x 8.3?m are presented, showing efficiency and near field/far field measurements of the higher order mode.

9466-12, Session 3

Laser beam characteristics of optical phased arrays

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Optical phased arrays (OPAs) are playing an important role in the next generation of high power laser systems. The coherent combination of several laser beams in tiled OPA configurations, as well as their propagation through the atmosphere has been successfully demonstrated. At the same time, very limited details of laser OPA beam quality can be found in scientific literature.

This paper is intended to fill the void by addressing the key laser OPA beam characteristics. We show how diffraction phenomenon determines the formation and propagation of laser radiation in OPAs, and defines their key characteristics, including the cumulative beam power, horizontal and vertical power in the bucket, Strehl value, central node power, M2 parameter, beam parameter product, etc. We also demonstrates the influence of OPA beam properties, such as the array fill factor and the presence of phase discontinuities, such as phase delays between the individual array apertures onto the resulting characteristics of the OPA laser beams.

9466-13, Session 4

Thermally and mechanically enhanced phosphate glasses for eye-safe lasers

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High power 1.5 μm radiation is of high interest in optical communications, military systems and medical systems. This wavelength is retina safe (also called eye-safe) and coincides with the low loss window of fused silica fibers. In recent years, the need for high beam quality for passive operation in open air applications have renewed interest in Er-doped bulk glasses as the gain material of choice for solid-state lasers. In glasses, the phosphate structure is known to produce high gain for Er. Unfortunately, the thermal and mechanical properties of a typical phosphate glass structure are low when compared to a crystal or even a silicate glass structure. In order to facilitate higher pump power levels for higher energy output, a stronger, more thermo-mechanically robust phosphate that maintains laser efficiency is needed.

With this target in mind, a study was initiated in order to strengthen a commercially available laser glass (SCHOTT LG940) by adding thermo-mechanical drivers to the starting composition. It is well known that the addition of certain elements in the periodic table to the amorphous glass structure will decrease the laser efficiency for other active ions in the lanthanide series. It is also known that Er^{3+} emission is significantly impacted by the host glass phonon energy. Thus, the main goal of the study is to produce a laser gain material that would have an increased thermo-mechanical figure of merit (FOM), simultaneously maintaining or increasing any laser FOM's. Secondly, we seek to understand the impact of the glass modifiers on Er manifolds and the resulting laser output efficiencies.

This report details a number of compositions that were designed and melted on a small scale in order to first check the stability. The compositions that produced a stable glass were then melted on a larger scale. All optical, physical and laser properties were measured on these glasses. Slope efficiencies and performance results for the glass(es) that met the targeted results will be presented.

9466-14, Session 4

Magneto-optical properties of fluorinated silicate glasses doped with rare earth ions

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Increasing power of new laser sources requires good isolation from harmful back reflection, which may destabilize the laser or even damage the internal laser cavity. While optical isolators for visible and 1-1.5 μm regions are in common use, new application require extension to long wavelength region. For example, there are many military sensors applications that require optical isolation at 2 micron, such as Tm and Ho-doped high-power fiber laser systems.

Optical isolators in the visible and near-IR spectral regions are mainly based on terbium doped gallium garnet crystal or Tb-doped bulk glasses or fibers. Pr ions are also perspective in those regions. However, for longer wavelength region, these ions are strongly absorptive. Limited availability of optical isolators in mid-IR stimulates the development of new materials.

The shortest absorption bands that determine availability of most common silicate glass matrices for IR application are absorption bands of hydroxyl contaminations that have maxima at 2.8, 3.6 and 4.5 μm. Therefore we have studied fluorinated silicate glasses that enable dramatic decrease of hydroxyl absorption and the use of glasses in the spectral range up to 3-3.5 μm. We present the results of optical and magneto-optical studies of fluorinated silicate glasses doped with different rare-earth ions such as Ce, Nd, Dy, Er, La and Yb. Both bulk glasses and fibers were fabricated and investigated using different dopant concentration. Verdet constant measurements were performed in the infrared region and the influence of high power on optical isolation properties was investigated.

9466-15, Session 4

Transition metal doped gallium nitride laser materials

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Transition metal doped crystals give rise to an important class of solid-state lasers. These lasers provide broadly tunable sources for many applications. Ti:Sapphire (Ti^{3+}:Al_2O_3) for example has found broad utility in both narrow-line tunable and ultra-short pulse systems. We report the growth and characterization of GaN as a laser host for transition metals. This emerging bulk semiconductor has several properties that make it a promising host for tunable lasers. GaN's wide band-gap and low energy phonon spectra yield a broader transparency than most oxides, from 390 to 7000nm. GaN has a hardness comparable to SiC and has a chemically stability comparable to diamonds. It is uniaxial with an index of 2.4 and relatively weak dispersion. Important for higher power lasers, the thermal conductivity of GaN is fifty times higher than YAG. Its trivalent gallium site readily accommodates high levels of metal doping. High ligand fields in GaN generate large splitting of the 3d5 tetrahedral electronic configurations. This leads to blue-shifting of the 3d transitions normally observed in oxides and chalcogenides. Recent experimental GaN growths using Hydride Vapor Phase Epitaxy doped with several different transition metals will be reviewed. Spectroscopic measurements relating to potential laser performance will be reported for samples doped with Iron and Manganese.

9466-16, Session 4

Frequency conversion with quasi-phase matched gallium nitride

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Broadband transparency, high thermal conductivity, and strong nonlinearity make gallium nitride a promising material for high power frequency conversion. We have fabricated quasi-phase matched (QPM) devices based on patterned inverted growth on commercial, c-axis, N-polar, GaN substrates. The desired QPM pattern is defined using lithographic masking and grown on using a combination of Metal-Organic Chemical Vapor Deposition and Hydride Vapor Phase Epitaxy processing. High fidelity periodically oriented GaN layers were grown on 10x10mm GaN substrates with QPM layer thicknesses up to 530 μm. Phase matching experiments with 32 ?m period structures are reported using a tunable nanosecond laser source. Second harmonic resonance is compared with predicted values based on birefringent dispersion measurements in bulk GaN samples. We will review fabrication issues and optical experiments on the first of these nonlinear frequency conversion devices.

9466-17, Session 4

Spectroscopic properties of Er-doped Y2O3 ceramic related to mid-IR laser transition

Tigran Sanamyan, Zackery D. Fleischman, U.S. Army Research Lab. (United States)

We have recently demonstrated efficient high power CW laser operation in Er doped Y_2O_3 at cryogenic temperature. The selection of laser host was based on the low-phonon nature of Y_2O_3, where the 4I11/2 4I13/2 transition is highly radiative. Further increases in mid-IR power scaling and efficiency require in-depth study and analysis of basic spectroscopic properties of the 4I11/2 ?4I13/2 laser transition, such as laser emission cross- sections, fluorescence quantum efficiency, fluorescence branching ratios and inter-ionic interactions in a wide dopant-concentration and temperature range. In

this work, we report the results of experimental measurements of quantum efficiency and branching ratio of the erbium initial laser state of 4I11/2 in Y_2O_3 ceramic at the temperature range of 10 - 300 K. A series of Er:Y_2O_3 samples with dopant concentration between 0.2-10 at.% were used for fluorescence and absorption measurements. The fluorescence from the energy states corresponding to the visible, IR, and mid-IR transitions were studied under short-pulsed diode laser excitation. Spectrally-narrowed fiber-coupled semiconductor laser modules emitting at ~ 808, 980, and 1530 nm with variable power density were used for fluorescence excitation of three different Er states. The energy transfer processes for both down- and up-conversion, affecting the Er:Y_2O_3 mid-IR laser operation, were analyzed. A comparison between the experimental and simulation results are presented as well.

9466-30, Session PSTue

Yb-fiber-MOPA based high energy and average power uplink laser beacon for deep space communication operating under Nested PPM format

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High average and peak power capable (~4kW, 240kW) laser beacons are needed for deep space optical communication uplinks to serve as absolute reference for precise pointing/tracking of the spacecraft during downlink laser communication. High-reliability silicon avalanche photo-detectors (Si-APD) are used on the spacecraft to detect the uplink beacon. For improved SNR in pointing/tracking, and reduced uplink laser power requirement, it is desirable to operate at shorter wavelengths near 1030nm, where near-IR Si-APDs have improved (>3X) spectral responsivity. Space qualifiable, highly sensitive detectors at 1064nm are also becoming available and at Yb cladding pumped fiber amplifiers exhibit higher Raman thresholds at longer wavelengths. Multiple apertures (~ 8 beams) are preferred to alleviate scintillation and improve fade characteristics due to the atmospheric turbulence.

A Yb LMA fiber amplifier based, turn-key 1030nm laser transmitter capable of operating with high average power and peak power (~500W, 9kW) is presented. The prototype, all-fiber, high TRL level laser transmitter is designed to meet all the single aperture requirements of an ultimate eight aperture deep space laser beacon system including capability to operate with Nested pulse position modulation (PPM) format. Nested PPM format consist of an inner modulation PPM-12 with 128nsec slot size and an outer modulation PPM-4 65.5usec slot size. In implementing inner modulation strong pre-pulse shaping is required where PPM pattern dependent pulse energy variation is minimized. Seven gain stages in the system can support high distributed-pre-pulse shaping losses. Outer modulation is implemented by directly modulating VBG locked pump lasers in the final two gain stages using ultra-fast high power diode drivers. A sophisticated multi-stage, ultra-fast loss of signal (LOS) and backward Raman/lasing protection is implemented for reliable operation. LOS detects any missing pulses in PPM pulse train that will cause detrimental overshooting. The modular design for laser transmitter allows for a straightforward conversion of the operating wavelength to 1064nm. System is expected to be capable of operating with 18kW of peak power at 1064nm.

9466-31, Session PSTue

Proposal of a defense application for a chemical oxygen laser

Kiwamu Takehisa, O2 Laser Lab. (Japan)

Defense application for a chemical oxygen laser (COL) is explained. Although a COL has not yet been successful in lasing, a potential to produce a giant pulse may be useful as a defense application. 1) A COL oscillator is considered to produce a giant pulse with the FWHM of ~0.05ms. This relatively long pulse gives a several-order higher damage threshold at the mirrors compared with a typical solid-state pulsed laser. Along with a simplicity of scalability, MJ class pulsed output is not impossible, needless to say, without electric power supply. While within 0.05ms, a supersonic aircraft can move only a few centimeters which is roughly equal to the spot size of the focused beam at ~30km away using a large-diameter focusing mirror. Therefore a large COL has a potential to shoot down an enemy fighter by a single shot without beam tracking.

Reference 1. K. Takehisa, “New concepts of realizing a chemical oxygen laser,” SPIE Vol. 9251, (2014).

9466-32, Session PSTue

Analysis and modeling of a high-power side diode pumped solid state laser system

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This paper summarizes the results of simulation of a module for side-pumping a Nd:YAG rod. The module consists of three laser diode arrays separated by 120o rotation angle around the laser rod, where each array contains 10 emitters producing a maximum output power of 15 W at 808 nm wavelength. This high power diode pumped solid-state (DPSS) laser system was modeled and implemented in both LASCAD and GLAD simulators. LASCAD model was used to simulate the laser output power as a function of the total input power and the output mirror reflectivity. The model predicted an output power of 140 W for a total input power of approximately 400 W with optical efficiency of 35 %, which is in a good agreement with the published experimental results and similar commercially available CW DPSS laser systems. Simulation in GLAD enabled a detailed analysis of the beam quality, beam size, and mode stability inside the resonator. GLAD models were used to simulate the pumping light distribution in the Nd:YAG rod for single diode element, single diode array, and three diode arrays. The GLAD shows that a stable multi-transverse mode “top hat” beam is formed after 30 passes through the resonator of the adopted high power DPSS laser system.

9466-18, Session 5

Stimulated Brillouin scattering in optical fibers with end reflections excited by broad-band pump waves with different spectral shapes

Mark S. Bowers, Robert S. Afzal, Lockheed Martin Aculight (United States)

Stimulated Brillouin scattering (SBS) is the main limitation on achieving high-power, narrowband laser light from fiber laser systems. One widely used technique for SBS suppression is modulating the laser radiation to broaden its linewidth to a value larger than the Brillouin linewidth, resulting in an increase in the SBS threshold. In this work, we present calculations for the first time of SBS in passive optical fibers pumped by broadband laser fields with different spectral shapes that includes the effects of laser feedback. The transient theory for SBS is used with the proper boundary condition for the backward-propagating field in the time domain to include a weak reflection of the laser field. It is shown that the spectral shape of the incident field and its overlap with the SBS gain spectrum affects the SBS signal. Numerical examples are presented for an incident laser field that is pulsed with a continuous, filled-in spectrum and a continuous-wave (CW) field with a sinusoidal phase modulation. For the pulsed field with a continuous spectrum and a reflection of 0.01% (-40dB) from the fiber end, the SBS threshold continuously increases as a function of the laser spectral width, but at a reduced slope compared to the threshold without

end reflections. For a CW field with a sinusoidal phase modulation and an end reflection of 0.01%, the SBS threshold drops significantly at discrete modulation frequencies where the laser and SBS gain spectra overlap. The implications of these results on the design of high-power fiber laser systems that utilize spectral broadening to suppress SBS are presented.

9466-19, Session 5

Mode-locked and Q-switched fiber lasers with graphene oxide based saturable absorber *(Invited Paper)*

Pu Wang, Jiang Liu, Beijing Univ. of Technology (China)

Graphene oxide, served as the precursor for graphene, has also been widely investigated for its own physical and chemical characteristics. The presence of oxygen-containing functional groups makes graphene oxide strongly hydrophilic and water soluble, which is different with graphene. In addition, although the oxygen functional groups destroy the gapless linear dispersion of Dirac electrons in graphene and make graphene oxide insulating, it has been demonstrated that graphene oxide also has a fast energy relaxation of hot carriers and strong saturable absorption, which is comparable with that of graphene. These properties make graphene oxide as potential saturable absorber material in pulsed fiber lasers. Here, we will review the research work of our group at pulsed fiber lasers with graphene oxide saturable absorber. Firstly, we will introduce a femtosecond erbium-doped fiber laser mode-locked with graphene oxide saturable absorber, which can be conveniently obtained from natural graphite by simple oxidation and ultra-sonication process. The laser directly generated 200 fs pulses at a repetition rate of 22.9 MHz and the average power was 5.8 mW. With the variation of net cavity dispersion, output pulses with pulse width of 0.2~3 ps were obtained at a repetition rate of 22.9~0.93 MHz. And then, the stable passively Q-switched operation by graphene oxide saturable absorber in the 1 μm ytterbium-, 1.5 μm erbium-, and 2 μm thulium-doped fiber lasers will be demonstrated as well. These results are comparable with those of graphene saturable absorbers and the superiority of easy fabrication and hydrophilic property of graphene oxide will facilitate its potential applications for ultrafast photonics.

9466-20, Session 5

Narrow-band, all-fiber 100W 20-ps Yb-doped fiber laser source

Robert A. Stegeman, Q-Peak, Inc. (United States); Wenyan Tian, Q-Peak Inc (United States); Ye Huang, Eric D. Park, Peter F. Moulton, Q-Peak, Inc. (United States)

A fully-fiberized, narrow bandwidth 1064-nm fiber laser system has been demonstrated and achieves over 100 Watts of average power with a bandwidth of 0.255 nm. The output consists of 15-ps pulses operating at a 100 MHz repetition rate. The repetition rate can be set to an arbitrary number. The output spectrum shows minimal amplified spontaneous emission and no additional nonlinear effects, such as Raman scattering or self-phase modulation.

The laser consists of a gain-switched diode laser and three amplifiers. Highly doped Yb-fiber has been used by minimizing fiber lengths to mitigate the nonlinear effects at high peak powers. Judicious use of spectral filtering is applied to minimize the presence of amplified spontaneous emisison in all of the amplifiers. The laser consists solely of commercially available parts and has the capability to add up to 600 Watts of pump power to the final amplifier stage.

Due to the high peak and average powers, in tandem with the narrow bandwidth, this laser can be an attractive source for discrete nonlinear optics (frequency conversion in nonlinear crystals) or broadband coherent light (supercontinuum) generation at high average powers.

9466-21, Session 5

Arbitrary phase modulation for optical spectral control and suppression of stimulated Brillouin scattering

Johan Nilsson, Achar V. Harish, Univ. of Southampton (United Kingdom)

We present results on the nonlinear optimization of arbitrary phase distribution which can be used to broaden the linewidth of a laser field to increase the stimulated Brillouin scattering (SBS) threshold in optical fiber. Some practical aspects of generation of such an arbitrary signal are discussed. The arbitrary modulation signal can be realized by an arbitrary waveform generator with sufficient bandwidth and can be used to drive the electro-optic phase modulator to produce top-hat shaped optical spectrum with optimum bandwidth ideal for increasing SBS threshold. Nonlinear optimization of the modulation signal is carried out with an ad-hoc algorithm designed to optimize a merit function which gives the best possible arbitrary signal which can make the optical spectrum a close approximation to top-hat shape. The problem is deceptively simple, but contains many pitfalls and trade-offs, which we will discuss.

9466-22, Session 6

Continuous-wave fiber Raman lasers cladding-pumped directly by diodes *(Invited Paper)*

Johan Nilsson, Tianfu Yao, Achar V. Harish, Jayanta K. Sahu, Univ. of Southampton (United Kingdom)

A fiber Raman laser emits at ~ 1019 nm when cladding-pumped directly by spectrally combined high power multimode laser diodes at ~ 975 nm and. With a commercial multimode graded-index fiber, we reached 20 W of laser output power with a record slope efficiency of 80%. With an in-house double-clad fiber, the beam quality improved to M2 = 1.9, albeit with a lower output power and slope efficiency due to higher fiber loss. We review our latest results and discuss prospects and possible improvements of this very promising technology. We believe this is the first demonstration of a fiber Raman laser cladding-pumped directly by diodes.

9466-23, Session 6

Diode pumped Tm/Ho composite Fiber 2.1 ?m laser

George A. Newburgh, U.S. Army Research Lab. (United States)

We present the results of an 800 nm diode-pumped solid Tm/Ho composite Large Area Mode fiber laser operating at 2.1 μm. The Tm/Ho composite laser fiber architecture consisting of a Tm doped cladding and a Ho doped core laser glass fiber was shown to efficiently generate and convert 1.9 μm radiation into 2.1 μm low order spatial mode radiation. Performance results and beam quality analysis of this first time demonstration of the composite laser fiber will be presented.

9466-24, Session 6

Extra-low Brillouin gain optical fiber derived from Er-doped sapphire ceramic

Mark Dubinskii, Tigran Sanamyan, Robert Pavlacka, U.S. Army Research Lab. (United States); Thomas W. Hawkins, Clemson Univ. (United States); Peter D. Dragic, Univ. of

Illinois at Urbana-Champaign (United States); John Ballato, Clemson Univ. (United States)

The first extra-low Brillouin gain Er-doped laser fiber was fabricated using the rod-in-tube fiber draw process. The rod-in-tube fiber preform used Er-doped sapphire ceramic as the preform core. Spectroscopic (both optical and acoustic) properties of Er in a sapphire-derived fiber core have been evaluated. First laser experiments in a simplified Master-Oscillator Power-Amplifier (MOPA) setup have been performed and their results are presented in our presentation.

9466-25, Session 6

Power scaling of resonantly-pumped double-clad fiber laser based on Yb-free Er-doped silicate glass

Jun Zhang, Radha Pattnaik, U.S. Army Research Lab. (United States); Shibin Jiang, AdValue Photonics, Inc. (United States); Mark Dubinskii, U.S. Army Research Lab. (United States)

Silica-based fibers are well suitable for application in highly power scalable Yb-doped lasers. Unfortunately, lasers on Er-doped silica-based fibers are not as amenable to power scaling due to low maximum core absorption - approximately an order of magnitude lower than that of Yb-doped fibers, which prevents utilization of large pump cladding diameters. In an effort to get around low solubility and clustering issue alternative glass systems can be more appropriate as a host for Er doping. For example, silicate glass has substantially richer chemical composition compared to silica glass and more complex glass network, which is more amenable to rare-earth doping at higher concentrations. Presented here are the results of spectroscopic and laser investigation of double-clad fibers based on Er-doped silicate glass. An ytterbium-free highly erbium-doped silicate glass fiber has been developed for high-power fiber laser applications at an eye-safe wavelength near 1.55-1.6 μm. We found out that Er ion concentration over eight times that of conventional silica fibers can be doped in the developed silicate glass without causing discernible fluorescence quenching or clustering. Due to much higher dopant concentration, the optimal length of Er-doped silicate gain fiber in the laser is much shorter than that of silica fiber reference used in our experiments. This is critically important for high-power narrow-band operation or pulsed laser applications. Our experiments also show that laser efficiency of over 75% can be obtained from Er-doped silicate fiber under the resonant pumping at 1535 nm.

9466-26, Session 7

Novel broadly tunable fiber laser system

Steven Bowman, U.S. Naval Research Lab. (United States); Christopher G. Brown, Univ. Research Foundation (United States)

The Naval Research Laboratory is developing a source capable of rapid tuning from the visible through the mid-infrared. The system design is based on sum and difference frequency generation in a monolithic, fiber architecture. The system incorporates short pulsed lasers at 1?m, 1.5?m, and 1.9?m; based on Ytterbium, Erbium, and Thulium fiber amplifiers. These amplifiers are injected by distributed feedback (DFB) laser diodes, which determine the precise wavelengths and pulse durations. Switching between multiple DFB diodes allows for rapid spectral tuning. The goal is to generate several kilowatts of peak power and 20W of average power for each fiber amplifier. The polarized output of these single-mode fiber lasers are combined into a novel switching nonlinear network. Sum and difference frequencies are generated via quasi-phase matching in Lithium Niobate, Gallium Nitride, and Gallium Arsenide crystals. This paper will review the design and performance of the system.

9466-27, Session 7

A passively q-switched compact solid state laser

Bhabana Pati, Eric D. Park, Q-Peak, Inc. (United States); Kenneth Stebbins, Q-Peak Inc (United States)

A compact laser with a volume of < 8 cm3 and a weight of < 100 gm finds its application in many fields from military to space based. There are several commercial lasers such as micro-chip lasers and fiber based lasers with low energy, ~?J per pulse at high repetition rates available at near IR wavelength. Micro-chip lasers have demonstrated 250 ?J of energy at 1064 nm from a fiber-end-pumped microchip laser with pulsewidths in the range of 100s of ps. The actual microchip laser is small but the fiber-coupled pump laser is large. With engineering, the fiber-coupled laser can be replaced by a diode bar with coupling optics. However, it will not be as compact as our design.

We have developed and built a small solid-state laser that produces 1 mJ of energy per pulse at a 10 -100 Hz repetition rate. The laser is passively Q-switched using a Cr:YAG saturable absorber to generate pulses < 10 ns. A nonlinear crystal doubles the frequency to generate green light at 523 nm. The laser is side pumped by a single bar diode laser using a unique pump cavity to homogenize the pump intensity in the laser rod. We designed the laser components in order to extract the largest fundamental mode for better beam quality. The laser components can easily be modified to change the output wavelength from 1.5 to 3 micron.

In this paper we will discuss the laser performance under different environmental conditions. We will also discuss and present laser performance at different output wavelengths by changing a few laser components. We will present data on laser power, energy per pulse, repetition rate, beam quality, pulse width and the dependency of these parameters on each other. We will discuss our future improved design to further reduce the foot print to ~ 4.4 cm3 and weight to under 60 gm.

9466-28, Session 7

Development of a compact laser target designator

Stephen T. Lee, Andrew G. Borthwick, Graham Morton, Ian McRae, Norman Imlach, George Gardiner, Gordon McKinlay, William Alexander, Mark Silver, Thales UK Ltd. (United Kingdom)

Lasers intended for application to man-portable and hand-held laser target designators are subject to significant constraints on size, weight, power consumption and cost. These constraints must be met while maintaining adequate performance across a challenging environmental specification. This dichotomy has led a number of companies to introduce low-energy 'marker' devices. These lasers can be used to mark a target for another cooperative platform but lack sufficient output energy to safely perform the function of terminal guidance (as defined for NATO by STANAG 3733). In addition the environmental performance of these marker devices is often seriously compromised. This paper presents work on a laser source with size, weight, power consumption and cost comparable to that of the lasers marketed for marking applications, while providing energy output performance that is compatible with full designator specification.

One of the challenges of operating a Nd^{3+}:YAG laser over a broad ambient temperature range is that of diode-pump-tuning. Around 808nm, laser diodes tune at approximately 0.3nm/°C. This system is specified to operate over an ambient temperature range of –46°C to +71°C, and the system electrical power consumption requirements preclude active temperature control. As a result the laser must tolerate a 32.8nm pump wavelength range. The optical absorption of Nd^{3+}:YAG varies dramatically over this wavelength range. This paper presents a laser that minimises the effect of this change on laser output.

A folded U-shaped geometry laser resonator is presented, made up of a corner cube at one end and a plane mirror substrate at the other. The action of the corner cube coupled with this configuration of end mirrors results in a resonator that is significantly less sensitive to misalignment of the end mirror and/or the corner cube.

This U-shaped resonator is then further folded to fit the laser into a smaller volume. Insensitivity of this compact folded resonator to mirror misalignments was analysed in Zemax via a Monte-Carlo analysis and the results of this analysis are presented.

The resulting laser output energy, pulse duration and beam quality of this athermally pumped, misalignment insensitive folded laser resonator are presented. Results for performance over an ambient temperature range of –46°C to +71°C are shown.

9466-29, Session 7

20.2W CW 2.118?m Ho:YAlO3 laser pumped by 1.915?m Tm-doped fiber laser

Ting Yu, Gang Bai, Zhongguo Yang, Weibiao Chen, Shanghai Institute of Optics and Fine Mechanics (China)

The emission wavelengths of holmium lasers lie in the eye-safe bandwidth region, and strong absorption lines of water and weak absorption lines of atmosphere are also located in the range. Therefore, they have great potential applications in a wide range of fields such as medical diagnoses and therapy, photoelectric countermeasure, laser range finder and laser radar. Furthermore, high-power quasi-continuous wave 2-?m lasers with high peak power are effective pump sources of optical parametrical oscillators and optical parametrical amplifications to generate radiation further in the mid-infrared region. The 2-?m lasers based on Ho-doped crystals end-pumped by 1.9-?m lasers can obtain high power at room temperature.

We report on the continuous wave operation of a Ho:YAP laser pumped by an all-fiber Tm-doped fiber laser, the pump laser wavelength is 1.915-?m and the output laser wavelength is 2.118-?m. The all fiber Tm-doped fiber laser is pumped by three high power clad-pumped LD, which are combined by a 3*1 combiner. The maximum output power of each LD is 70w.The double-clad Tm-doped fiber has a dimension of 25/250?m with the core/clad NA 0.09/0.46, cooling by a water cooled heat-sink. And a pair of multi-mode FBGs is used as cavity. After striping the pump light?the max output power is 70W with 200W pumped power, and the output laser wavelength is 1.915--?m. And this laser is used as pump laser to a Ho:YAP laser system. The output is coupled into the Ho:YAP crystal by a pair of collimate lens. The solid-state Ho:YAP laser uses a flat-concave cavity structure. With 30% transmission of output coupling, the compact Ho:YAP laser generated 20.2W continuous wave output for 33.3W absorbed pump power, corresponding to a slope efficiency of 72.53%, an optic-to-optic efficiency of 60.67%. The lasing wavelength was 2118.4nm with a line-width of 0.159nm. And the output beam quality of M2 was 1.11 at 8.83W output power level.

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9467-1, Session 1

Epidermal and bioresorbable electronic systems for clinical medicine *(Invited Paper)*

John A. Rogers, Univ. of Illinois at Urbana-Champaign (United States)

Recent research has established a set of foundational materials and device designs for integrated circuits and sensor systems that can (1) adopt the thicknesses and mechanical properties of the skin, and (2) dissolve at controlled rates in biofluids. The former, which we refer to as epidermal electronics, can softly laminate onto the surface of the skin to provide advanced measurements of physiological health. The latter, which represents a subset of a technology that we refer to as transient electronics, can insert into the body for therapeutic or diagnostic purposes in the context of natural processes such as wound healing. This talk describes these core technologies, with an emphasis on examples of their clinically relevant modes of use, as demonstrated through studies on animal models and human subject volunteers.

9467-2, Session 1

Edible Electronics: materials and devices for next-generation medical implants *(Invited Paper)*

Christopher J. Bettinger, Carnegie Mellon Univ. (United States)

Electronic medical implants serve as a key pillar in many therapeutic strategies. Classes of implantable devices include biosensors, controlled release systems, and tissue stimulation devices. While the sophistication of these implants has increased over recent years, there are many persistent challenges that may limit the prospective impact of permanent implantable device-based therapies. These include risk of infection, chronic inflammation, and costly surgical procedures. This talk will introduce the idea of edible electronic devices as a strategy to overcome many of these challenges. Two specific innovations will be discussed in this talk. First, the performance of edible batteries fabricated from biologically-derived melanin pigments will be examined. Second, the use of ultra-compliant electronically active hydrogels that integrate edible devices with soft tissue will be discussed. Prospective medical applications for edible electronic will be highlighted.

9467-3, Session 1

A strategy for establishing stable contact between machine/biological tissue *(Invited Paper)*

Sungwon Lee, The Univ. of Tokyo (Japan)

In order to precisely measure the electrical signals from the human body, it is crucial to establish stable, soft, and nonallergic contacts between the targeted biological tissue and the probes from the devices as well as the good performance of the device itself. So far, it has been difficult to form a stable interface between them, especially when the surface of the biological tissue is wet and/or the tissue exhibits motion. Here we suggest one simple way to solve the difficulty by designing and fabricating smart, stress-absorbing electronic devices that can adhere to wet and complex tissue surfaces and allow for reliable, relatively long-term electronic measurements of vital signals. A multielectrode array (MEA) coupled with an organic-transistor active matrix is manufactured on an ultrathin polymeric substrate show how this design can absorb the stress under extreme deformation. The surface of each electrode is coated with a photopatternable adhesive gel. The MEA could be attached to the surface of a moving body, resulting in good conformal contact for more than 3 h. We also succeed to integrate with organic amplifier and succeed to magnify the bio signal almost 100 times amplified. Furthermore, arrays of highly sensitive, stretchable strain sensors are fabricated using a similar electronic design. These could be attached on human skin to detect the strain induced by the motion of the joint.

9467-4, Session 1

Molecularly stretchable electronics for mechanically robust and wearable semiconductor devices *(Invited Paper)*

Darren J. Lipomi, Univ. of California, San Diego (United States)

The term “plastic electronics” masks the wide range of mechanical behavior possessed by films of ϖ-conjugated (semiconducting) small molecules and polymers. Mechanical compliance can be influenced strongly by differences in structure that appear minor. For example, poly(3-heptylthiophene) (P3HpT) is an order of magnitude more elastic than is poly(3-hexylthiophene) (P3HT). There is also an apparent trade-off between electronic performance and mechanical compliance in films of some of the best-performing conjugated polymers and polymer-fullerene blends, which fracture at tensile strains not significantly greater than those at which conventional inorganic semiconductors fail. The design of materials that can be deformed significantly would facilitate roll-to-roll production, mechanical robustness for potable applications, conformal bonding to curved surfaces (i.e., for implantable biomedical devices), and would enable large-scale solar farms based on ultrathin organic modules that can survive forces of the outdoor environment. This seminar describes my group’s efforts to understand and control the structural parameters that influence the mechanical properties of modern conjugated polymers. Our conclusions include the strong effect of the side chain in determining the elasticity, ductility, and adhesion of polymers and their blends with fullerenes, and how this effect can be predicted by theory. Ultra-compliant materials are used for the first time in solar cell that can be stretched and conformed to hemispherical surfaces without damage. We also describe the synthesis of all-conjugated, segmented copolymers, along with stretchable fabrics of semiconducting nanowires, whose goal is to maximize both electronic properties and mechanical compliance. Mechanical, electronic, and spectroscopic evidence suggest that compliance and electronic performance need not be in competition, and could inform the engineering of the next generation of semiconducting polymers for mechanically tough, ultra-flexible, and stretchable applications.

9467-5, Session 1

Soft electronics for soft robotics *(Invited Paper)*

Rebecca K. Kramer, Purdue Univ. (United States)

As advanced as modern machines are, the building blocks have changed little since the industrial revolution, leading to rigid, bulky, and complex devices. Future machines will include electromechanical systems that are soft and elastically deformable, lending them to applications such as soft robotics, wearable/implantable devices, sensory skins, and energy storage and transport systems. Current "soft electronics" utilize polymeric electrode materials, resulting in increased flexibility and decreased obscuration compared to conventional metal electrodes. However, these conductive polymers often have sheet resistances far in excess of metals, leading to significant losses and limited stretchability. The use of liquid-metal alloys encased in hyperelastic polymers addresses both of these challenges and compliments many flexible/stretchable applications by exploiting the inherent properties of liquid-metals, such as their metallic conductance, deformability, and potential for self-healing and shape-reconfiguration.

9467-6, Session 1

Liquid metals as ultra-stretchable, soft, and shape reconfigurable conductors *(Invited Paper)*

Michael D. Dickey, North Carolina State Univ. (United States)

This talk will discuss work in our group to pattern and actuate liquid metals for stretchable, reconfigurable, and transient electronics. The metal is an alloy of gallium. These alloys are noted for their low viscosity, low toxicity, and negligible volatility. Despite the large surface tension of the metal, it can be molded into non-spherical 2D and 3D 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. 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. The ability of the oxide to reform instantaneously also allows the metal to self-heal in response to damage. In addition, the ability to remove the oxide electrochemically provides a new means to control the shape of the metal for reconfigurable and transient electronics. We show that the oxide is one of the best surfactants ever reported and can tune the surface tension of the metal over an unprecedented range by using electrochemical reactions at the surface of the metal.

9467-7, Session 1

Transformational electronics are now reconfiguring *(Invited Paper)*

Jhonathan Rojas, Aftab Hussain, King Abdullah Univ. of Science and Technology (Saudi Arabia); A Arevalo, King Abdullah Univ of Science and Technology (Saudi Arabia); Ian G Foulds, The University of British Columbia, Okanagan Campus (Canada); Galo Torres Sevilla, Joanna Nassar, Muhammad M. Hussain, King Abdullah Univ. of Science and Technology (Saudi Arabia)

For nearly two decades flexible organic electronics have been explored for display and sensor (such as RFID tag) applications. At the same time, for nearly a decade JA Rogers et al. has spearheaded flexing of inorganic electronics by making them ultra-thin. Recently new techniques have been demonstrated including ours where bulk mono-crystalline silicon based electronics have been flexed while retaining their inherent high performance, ultra-large-scale-integration density, cost effectiveness and such. We deploy two techniques: trench-protect-peel-reuse and soft etch back. These techniques have shown maturity and reliability in process consistency and device characteristics. While flexible electronics is slowly approaching mass commercialization effort, stretchable electronics based on polymeric material has made its move. Again JA Rogers et al. has shown fractal design based stretching of silicon and other inorganic electronics. Recently we have shown unprecedented 800% stretching from copper metallic interconnect. For the last two years another area of such electronics has gained momentum under JA Rogers' leadership: transient or dissolvable electronics. In such electronics after certain period electronics can be dissolved. Taking this progress to next level we have studied polymer assisted programmable self-destruction of inorganic electronics. Moving forward we have engineered completely CMOS compatible process technology for hybrid integration of organic-0D nanomaterials-1D nanowires/nanotubes and 2D atomic crystal structure materials (which are inherently flexible due to their chemical bonding or low dimension) with ultra-thin flexible and stretchable inorganic electronics to transform any traditional electronics into monolithic in-plane and 3D out-of-plane electronic systems whose applications areas are wide and previously unimaginable.

9467-8, Session 1

Low cost, high throughput cut-and-paste manufacture of multifunctional epidermal electronic systems *(Invited Paper)*

Nanshu Lu, The Univ. of Texas at Austin (United States)

Epidermal electronic system (EES) is a class of non-invasive and non-obstructive skin mounted sensors with mechanical properties matching human epidermis. They are considered the most intimate and comfortable wearable sensors for vital sign and physiology monitoring including electrocardiogram (ECG), electromyogram (EMG), skin temperature, skin hydration and so on. Conventional manufacturing process of EES includes photolithography, metal deposition, dry and wet etching within cleanroom facilities. The high cost of manpower, materials, photo masks, and facilities associated with such process greatly hinders the commercialization potential of disposable EES. There has been little improvement of the manufacturing method since EES was first published in 2011. Here we report a low cost, bench top, "cut-and-paste" method to complete the manufacture of highly customized EES within minutes. This method works for all types of thin metal, graphene, and polymeric sheets and the resulted EES can be highly multimaterial and multifunctional. Our "cut-and-paste" EES has been successfully applied to measure ECG, EMG, skin temperature, skin hydration, as well as skin deformation. Negligible or no difference in functionality and performance was found between EES manufactured by conventional and "cut-and-paste" methods. In addition to EES, We have also extended our "cut-and-paste" method to manufacture stretchable electronics based on brittle ceramic materials. A vast range of applications of the "cut-and-paste" manufacturing method including the manufacture of stretchable circuit boards are anticipated.

9467-9, Session 1

Flexible phosphorene devices and circuits *(Invited Paper)*

Weinan Zhu, The Univ. of Texas at Austin (United States); Maruthi N. Yogeesh, Univ of Texas at Austin (United States); Deji Akinwande, The Univ. of Texas at Austin (United States)

Two dimensional atomic sheets, such as graphene and Transition Metal Dichalcogenides (TMDs), have been widely studied as the ideal candidates in flexible nanoelectronics applications. However, for both gapless graphene and wide-gap TMDs, challenges for achieving high carrier mobility and high current on/off ratio simultaneously seems difficult to overcome. Recently, graphene-like few-layer black phosphorus, with high hole transport mobility along armchair direction and thickness-dependent band gap, has become a new promising candidate for future high frequency and low power flexible electronics.

In this work, we present the first realization of few-layer black phosphorus field effect transistors (BP-FETs) and fundamental circuit units on flexible substrate. Dielectric capping was applied to resolve the air stability issue of phosphorene, resulting in strong am-bipolar transfer characters with very small hysteresis (<60mV). For phosphorene of 5nm to 15 nm thick, high room temperature hole-mobility and current on/off ratio are > 300 cm2/Vs and > 104, respectively. Besides the outstanding device performance, basic circuit units have been realized with appealing performance, including digital inverter, frequency doubler, inverting and non-inverting amplifiers. Our results in this work indicate that few layer black phosphorene has the potential to be most compelling nanomaterial for flexible nanoelectronics.

9467-10, Session 1

Transfer printing methods for fabricating nanowire devices on diverse substrates *(Invited Paper)*

Xiaolin Zheng, Stanford Univ. (United States)

Fabrication of nanowire (NW) electronic devices on flexible, transparent, ultrathin, or biocompatible substrates will impact a range of technologies, such as flexible displays, solar cells, and biosensors. Previous efforts have successfully fabricated flexible/transparent horizontal NW devices on plastics, glasses and thick polymer sheet by conducting lithography directly on these substrates. However, the choice of substrates is severely limited by their compatibility with lithography. Hence, new methods are needed to remove these fabrication constrains such that NW devices can be realized on more nonconventional substrates, such as paper, fabric, and metal foils. Moreover, it is highly desirable to fabricate vertical NW devices on diverse substrates to increase the device density and improve the device performance such as light absorption and gating properties. This presentation will introduce two transfer printing methods we have developed toward these goals. The first method is a simple, versatile, and wafer-scale water-assisted transfer printing method (WTP) that enables integration of NW devices onto diverse nonconventional substrates which were not easily accessible before, such as paper, plastics, tapes, glasses, polydimethylsiloxane (PDMS), Al foils, and ultrathin polymer substrates. The WTP method relies on a phenomenon of water intervening at the interface between two hydrophilic surfaces. The transfer yield is nearly 100%, and the transferred devices maintain their original geometries and electronic properties with high fidelity. The second method enables transfer of vertical SiNW arrays with uniform length onto adhesive substrates by the assistance of creating a horizontal crack throughout SiNWs. The crack is formed by adding a water soaking step between consecutive Ag-assisted electroless etching processes of Si. The crack formation is related to the delamination, redistribution and reattachment of the Ag film during the water soaking and subsequent wet etching steps. Moreover, the crack facilitates fabrication of vertical NW devices.

9467-11, Session 1

Stretchable inorganic nanomembre electronics for healthcare devices *(Invited Paper)*

Dae-Hyeong Kim, Donghee Son, Jaemin Kim, Seoul National Univ. (Korea, Republic of)

Recent advances in prosthetic and implantable devices comprising microelectronics and nanomaterials have attracted great attention from researchers involved with biomedical application. However, conventional devices integrated on inherently rigid substrate prevent from solving unique integration challenges for implantable devices and prosthetic skin. Here, we describe novel materials and design strategies for constructing multifunctional prosthetic skin and bioresorbable stent which incorporate variety of flexible/stretchable sensors and actuators for their unique functionalities. The multifunctional prosthetic skin is instrumented with ultrathin, single crystalline silicon nanoribbon strain, pressure, and temperature sensor arrays as well as associated humidity sensors, electroresistive heaters, and stretchable multi-electrode arrays (MEA) for nerve stimulation. The bioresorbable stent comprises drug-infused functionalized nanoparticles to enable flow sensing, temperature monitoring, data storage, inflammation suppression, localized drug delivery, and hyperthermia therapy. Quantitative analyses of sensing and actuating performances of these systems under various conditions verify the individual components and in vivo experiments of both systems demonstrate the validity of their system-level functions. These systems combine the cutting edge of flexible, stretchable and transient electronics to provide new opportunities and insights in biointegrated electronic devices.

9467-12, Session 1

Paper electronics: the next flexible, foldable,and stretchable electronics *(Invited Paper)*

Jr-Hau He, King Abdullah Univ. of Science and Technology (Saudi Arabia); Der-Hsien Lien, Po-Kang Yang, National Taiwan Univ. (Taiwan); Chun-Ho Lin, King Abdullah Univ. of Science and Technology (Saudi Arabia)

Recently, with more interests in cheap, simple and energy-saving fabrication processes for microelectronics, much attention has been focused on making electronic devices using printing techniques on any desired substrates, especially those so-called flexible electronics. Printed and flexible electronics is expected to reach $45 billion by 2016. Paper, as a flexible, foldable, cost-efficient and mass productive substrate, has shown diverse applications for flexible electronics to meet such demand. Recently, we have demonstrated the first nonvolatile resistive memory using the papers as substrates by means of all-printing techniques. Using a sequence of inkjet and screen printing techniques, a simple metal-insulator-metal device structure is fabricated on paper as a resistive random access memory with a potential to reach gigabyte capacities on an A4 paper. We show that the paper memory can be labeled on electronics or living objects for multi-functional, wearable, on-skin, and biocompatible applications. Besides the fabrication of electronics on paper, we also put the algorithm of Origami art into the device design for the flexible electronics taking advantage of the foldability. For example, the concept of Miura-origami can be applied to fabricate photodetectors, which can promise super stretachability (strain > 1000%), twisting capability and omnidirectionality. The concept of origami can be applied on other devices, such as solar cells and nanogenerators, to boost their conversion efficiencies. Discovering renewable and sustainable power sources is indispensable for the development of green electronics and sensor networks. Recently we present the first origami triboelectric nanogenerators (TENGs) using paper as the starting material, with high degree of flexibility, light weight, low cost, and recyclability. Slinky and doodlebug shape TENGs can be easily fabricated by properly folding printer papers. These findings will pave a way for future energy harvesting and sensor design, especially for the development of green flexible electronics.

9467-13, Session 2

20 kHz ultrasound assisted treatment of chronic wounds with concurrent optic monitoring *(Invited Paper)*

Christopher R. Bawiec, Youhan Sunny, Drexel Univ. (United States); David Diaz, Sumati Nadkarni, Drexel University (United States); Michael S. Weingarten, Drexel Univ. College of Medicine (United States); David J. Margolis, Univ. of Pennsylvania (United States); Leonid A. Zubkov, Michael T. Neidrauer, Peter A. Lewin, Drexel Univ. (United States)

We report the results of a second clinical pilot study (n=17) involving treatment of chronic venous ulcers using a novel, fully wearable, tether-free, ultrasound applicator operating at 20 kHz and generating pressure amplitudes close to 55 kPa (about 100 mW/cm2, ISPTP). Patients with venous ulcers that have been documented for a minimum of 8 weeks were enrolled from the Drexel Wound Healing Center according to the protocol approved by the University IRB, and randomly assigned into treatment or control groups. Patients were treated weekly (15 minutes) for a maximum of 12 visits or until wound closure. The treatments were given in addition to standard of care compression therapy as ordered by the physician. Of the patients attending at least 3 sessions (n=16), the ultrasound treated group had statistically improved ($p<0.04$) rate of wound size change (reduction of 8.2%/wk) compared to the rate of wound size change for the control group (increase of 7.5%/wk on average). Concurrently with ultrasound treatment, non-invasive optical diffuse spectroscopy was successfully used to monitor the ulcers' healing status by measuring tissue oxygenation and blood flow in the capillary network. The optical system provided an early prognosis tool for the monitoring of healing outcomes, potentially enabling an agile intervention and customization of wound management. This study supports the notion that active low frequency ultrasound treatment of chronic venous ulcers combined with the current standard of care promotes the healing process and can potentially be performed at the patient's home, away from the clinical setting. Acknowledgement: NIH 5R01EB009670.

9467-14, Session 2

Guiding tissue regeneration with ultrasound in vitro and in vivo *(Invited Paper)*

Diane Dalecki, Univ. of Rochester (United States); Eric S. Comeau, Carol H. Raeman, Sally Z. Child, Laura Hobbs, University of Rochester (United States); Denise C. Hocking, Univ. of Rochester (United States)

Developing new technologies that enable the repair or replacement of injured or diseased tissues is a major focus of regenerative medicine. This presentation will discuss three ultrasound technologies under development in our laboratories to guide tissue regeneration both in vitro and in vivo. A critical obstacle in tissue engineering is the need for rapid and effective tissue vascularization strategies. To address this challenge, we have developed an ultrasound technology for microvascular tissue engineering. Acoustic radiation forces associated with ultrasound standing wave fields provide a rapid, non-invasive approach to spatially pattern cells in three dimensions without affecting cell viability. Ultrasound-induced patterning of endothelial cells leads to the rapid formation of microvascular networks throughout the volumes of three-dimensional hydrogels, and the morphology of the resultant microvessel networks can be controlled by design of the ultrasound field. A second technology under development uses ultrasound to noninvasively control the microstructure of collagen fibers within engineered tissues. The microstructure of extracellular matrix proteins provides signals that direct cell functions critical to tissue regeneration. Thus, controlling collagen microfiber structure with ultrasound provides a noninvasive approach to regulate the mechanical properties of biomaterials and control cellular responses. The third technology employs therapeutic ultrasound to enhance the healing of chronic wounds. Recent studies have shown increased granulation tissue thickness and collagen deposition in murine dermal wounds exposed to pulsed ultrasound (1-MHz, 0.4 MPa). In summary, ultrasound technologies offer noninvasive approaches to control cell behaviors and extracellular matrix organization and thus hold great promise to advance tissue regeneration.

9467-15, Session 2

Ultrasound induced neurostimulation *(Invited Paper)*

Randy L. King, U.S. Food and Drug Administration (United States)

Developments in the use of ultrasound to stimulate and modulate neural activity have raised the possibility of using ultrasound as a new investigative and therapeutic tool in brain research. The phenomenon of ultrasound induced neurostimulation has a long history dating back many decades, but until now there has been little evidence demonstrating a clearly localized effect in the brain, a necessary requirement for the technique to become genuinely useful. Here we report clearly distinguishable effects in sonicating rostral and caudal regions of the mouse motor cortex. Motor responses measured by normalized EMG in the neck and tail regions changed significantly when sonicating the two different areas of motor cortex. Response latencies varied significantly according to sonication location suggesting that different neural circuits are activated depending on the precise focus of the ultrasound beam. Taken together our findings present good evidence for being able to target selective parts of the motor cortex with ultrasound neurostimulation in the mouse, an advance that should help to set the stage for developing new applications in larger animal models and ultimately humans.

9467-16, Session 2

Targeted delivery of GABA via ultrasound-induced blood-brain barrier disruption blocks somatosensory-evoked potentials *(Invited Paper)*

Nathan McDannold, Yongzhi Zhang, Chanikarn Power, Costas Arvanitis, Natalia Vykhodtseva, Brigham and Women's Hospital (United States); Margaret Livingstone, Harvard Medical School (United States)

When focused ultrasound pulses are combined with a microbubble ultrasound contrast agent, one can temporarily disrupt the blood-brain barrier (BBB) and enable the delivery of drugs to precisely selected targets or volumes. This method can enable new and better treatments for brain tumors and other CNS disorders. The method can also enable the delivery of substances that modulate brain function. This study demonstrated that targeted delivery of the inhibitory neurotransmitter gamma-Aminobutyric acid (GABA), a small molecule (103 Da) that normally does not reach the brain with systemic administration, can temporarily block brain activity after ultrasound-induced BBB disruption.

Focused ultrasound exposures (10 ms bursts applied at 1 Hz for 60 s; pressure amplitude in water: 0.64-0.71 MPa) were delivered immediately after the administration of Definity microbubbles (20 or 40 μl/kg) to disrupt the BBB. The focal point was targeted to 10 overlapping targets on and around the somatosensory motor cortex (2 mm lateral, 2 mm posterior to bregma) under MRI guidance in 8 rats. BBB disruption was confirmed using Gd-DTPA MRI contrast agent (Magnevist, 0.25 ml/kg). After the sonications, electrodes were implanted into the thigh muscle to electrically stimulate the sciatic nerve (stimulation voltage: 9-20 V). Somatosensory evoked potentials (SSEP) were recorded transcranially before and after intravenous GABA at doses ranging from 0.8 to 519 mg/kg. The SSEP recordings were repeated in three animals at 24h after sonication and one animal at 5 days. SSEP measurements were obtained in four control animals who received GABA but not ultrasound-induced BBB disruption.

The amplitude of the SSEP recordings in the animals who received GABA and ultrasound-induced BBB disruption were reduced by 6-99%. There was a good correlation (R?: 0.69-0.90) between the percent suppression in SSEP magnitude and GABA dose. This suppression also correlated with the degree of BBB disruption – for similar GABA doses, animals that had less suppression also had weaker enhancement in MRI after Gd-DTPA administration. For relatively small doses of GABA (0.8-64 mg/kg), the duration of the suppression lasted between 2-20 min, with higher doses resulting in longer durations. At high doses (422 mg/kg and above) the suppression lasted the length of the recordings (up to 100 min). No significant suppression was observed after GABA administration in control animals or in recordings performed 24h or 5d after the sonications.

This work demonstrates an ultrasound-based method to block neuronal function at targeted structures. It has some advantages over other ultrasound "neuromodulation" techniques: the ability to use contrast MRI to definitively confirm where the suppression is targeted, the ability to suppress multiple targets simultaneously, the ability to titrate the GABA dose to control the level of suppression, and the ability to recover the animal from anesthesia and transiently block function in a freely behaving animal. Since the effects of GABA and other neurotransmitters have been studied for decades, the mechanisms of the suppression are well understood. We anticipate that the use of neurotransmitters in this way can be useful for noninvasively mapping brain function and potentially for surgical planning or novel therapies.

9467-17, Session 2

Ultrasound-based biomodulation mechanisms, devices and applications in medicine *(Invited Paper)*

George K. Lewis, ZetrOZ, Inc. (United States)

An exciting area of research over the last ten years has been elucidating the effects of low intensity mechanical forces on biological systems. Ultrasound is an established, effective therapeutic modality for introducing mechanical forces into the body. Static and dynamic mechanical forces can impact cell migration, protein expression profiles, cell fate, and membrane permeability. While high intensity mechanical forces are successfully used in cell ablation, low intensity mechanical forces increase transport kinetics, activate mechanically sensitive membrane proteins, and cause cells to experience cycles of compression and rarefaction. This concept of using low intensity ultrasound over long durations has been named "Sustained Acoustic Medicine" (SAM). Studies of low intensity ultrasound for enhanced drug delivery in the brain relied upon miniaturized needle-focused ultrasonic delivery technology to control diffusive and convective transport phenomena in poroelastic neuronal tissue. SAM has also been used as a wearable physiotherapy to improve healing outcomes. Ultrasound has an established history in bone regrowth and regeneration. Recent research has demonstrated the ability of ultrasound to assist in tendon healing and regrowth, as well as relieve painful muscle spasms. Ongoing research efforts in biology and technology are expanding our knowledge about how ultrasound can be used to treat conditions such as osteoarthritis and back pain, and the design of delivery platforms that are self-applied and wearable, respectively. Low intensity mechanical forces delivered with SAM are a success story in the field of translational research using low intensity energy deposition for biomodulation.

9467-18, Session 3

Antimicrobial blue light therapy for microbial wound infections *(Invited Paper)*

Tianhong Dai, Massachusetts General Hospital (United States) and Harvard Medical School (United States)

The threat of antibiotic resistance has necessitated the search for alternative approaches against microbial wound infections. Antimicrobial blue light has been attracting increasing attention due to its intrinsic antimicrobial effect without the involvement of exogenous photosensitizers. In this study, we investigated the effectiveness, safety and mechanism of action of antimicrobial blue light against microbial wound infections. Gram-negative bacteria Pseudomonas aeruginosa, Acinetobacter baumannii and yeast Candida albicans were used as the representative species. In vitro study demonstrated that antimicrobial blue light at 415 nm selectively inactivated microbes in both planktonic cultures and biofilms over human keratinocytes. Transmission electron microscopy revealed blue light-mediated ultrastructural damage in microbial cells. High-performance liquid chromatography (HPLC) confirmed the presence of endogenous porphyrins, which are assumed to be responsible for the antimicrobial activity of blue light. No elevated resistance to antimicrobial blue light was observed after 10 cycles of sublethal blue light inactivation of the microbes. In vivo study was also carried out by using a mouse model of third degree burns infected with above microbes. Blue light was initiated at 30 min or 48 h after bacterial inoculation. In vivo bioluminescence imaging technique was used to monitor in real time the extent of infections. Our results showed that antimicrobial blue light successfully prevented the development of infection in mouse burns, and successfully eradicated the infections in mouse burns when infections developed. We concluded that antimicrobial blue light is a viable approach against microbial wound infections.

9467-19, Session 3

Therapeutic efficacy of photobiomodulation for the treatment of autoimmune demyelination *(Invited Paper)*

Jeri-Anne Lyons, Univ. of Wisconsin-Milwaukee (United States)

Multiple sclerosis (MS) is an inflammatory demyelinating disease of the central nervous system (CNS) characterized by an immune-mediated attack on CNS axons. While early disease is due to autoimmunity, disease progression is due to increased oxidative stress and death of the axon. Current therapies are only partially effective because they only target the immune response and do not protect against oxidative stress. In addition to destructive autoimmunity, a role of protective regulatory T cells in preventing disease is recently recognized. Experimental Autoimmune Encephalomyelitis (EAE) is the primary animal model for MS, sharing clinical and histopathologic similarities with MS. The EAE model has been instrumental in developing therapeutic strategies. Previous data from our lab demonstrated the therapeutic efficacy of photobiomodulation with 670nm light in the amelioration of EAE through down-regulation of pro-inflammatory mediators, up-regulation of anti-inflammatory cytokines, and protection of CNS cells from apoptotic cell death. A clear understanding of the mechanism by 670 nm light induced photobiomodulation is critical to the approval of this novel therapeutic strategy for the treatment of MS. Data will be presented that demonstrates the induction of protective regulatory T cells by 670 nm light. These cells are expected to play a direct role in the protection against clinical disease afforded by 670 nm light. A deeper understanding of these mechanisms may suggest other therapeutic applications of far red/near infrared light.

9467-20, Session 3

Red/near-infrared light-emitting diode therapy for traumatic brain injury *(Invited Paper)*

Margaret A. Naeser, VA Boston Healthcare System (United States); Paula I. Martin, Michael Ho, Maxine H. Krengel, Yelena Bogdanova, VA Boston Healthcare System (United States) and Boston Univ. School of Medicine (United States); Jeffrey A. Knight, VA Boston Healthcare System (United States); Megan K. Yee, VA Boston Healthcare System (United States) and Boston Univ. School of Public Health (United States); Ross Zafonte, Spaulding Rehabilitation Hospital (United States) and Harvard Medical School (United States); Judith A. Frazier, Spaulding Rehabilitation Hospital (United States); Michael R. Hamblin, Wellman Ctr. for Photomedicine (United States) and Harvard Medical School (United States); Bang-Bon Koo, Boston Univ. (United States)

This invited paper reviews our research with scalp application of red/near-infrared (NIR) light-emitting diodes (LED) to improve cognition in chronic, traumatic brain injury (Naeser, Zafonte, et al., 2014). Application of red/NIR, laser/LED light improves mitochondrial function (especially in hypoxic/compromised cells) promoting increased ATP, important for cellular metabolism. Nitric oxide is released locally, increasing regional cerebral blood flow (rCBF). Eleven chronic, mTBI participants with closed-head injury and persistent cognitive dysfunction were treated for 18 outpatient sessions (MWF, 6 Wks), starting at 10 Mo to 8 Yr post-mTBI (MVA, sports-related, IED blast injury). LED therapy is non-invasive, painless, non-thermal (FDA-cleared, non-significant risk device). Each LED cluster head (2.1" diameter, 500mW, 22.2mW/cm2) was applied for 10 min (13J/cm2) to 11 scalp placements: midline, from front-to-back hairline; and bilaterally on dorsolateral prefrontal cortex, temporal, and parietal areas. Testing was performed pre- and post- LED at 1 Wk, 1 and 2 Mo post- 18th treatment. Significant linear trend was observed for LED effect over time - executive function- Stroop Trial 4 Inhibition Switching (p=.003); California Verbal Learning Test-II, Long Delay (20 min later) Free Recall (p=.006). Fewer PTSD symptoms were reported. Ongoing studies from VA Boston will also be presented, including TBI patients treated with transcranial LED (26 J/cm2); and treated with only intranasal red, 633nm/NIR, 810nm diodes placed in each nostril (25 min, 6.5mW, 11.4J/cm2). Intranasals are hypothesized to deliver photons to hippocampus. Results are similar to Naeser et al. (2014). New, Actigraphy sleep data show increased sleep time (average, +1 Hr/night) post- 18th transcranial, or intranasal LED treatment. Pre- and Post- fMRI scans in chronic stroke patients treated with transcranial LED suggest photons are promoting increased rCBF in cortical areas where targeted. LED treatments may be self-administered at home (Naeser et al., 2011). A sham-controlled study with Gulf War Illness Veterans is underway.

9467-120, Session 3

Laser phototherapy: the future of medicine *(Invited Paper)*

Terrance L. Baker, Sollay Cosmetic Medical & Laser Ctr. (United States)

The development of advanced surgical techniques and pharmaceuticals have dramatically contributed to the improvement of global health. However, surgical procedures and pharmaceutical agents are costly and have the potential to create severe side effects and complications for patients.

Interdisciplinary researchers are looking for non-pharmaceutical therapies and non-surgical interventions to provide effective treatment for a broad range of medical conditions. This presentation describes one of the most promising therapies - laser phototherapy.

After more than 50 years of clinical use, no serious side effects or adverse reactions of using phototherapy as a medical treatment modality have been observed. Phototherapy effects the natural and basic mechanism of virtually all human cells and restores impaired function, triggering a subsequent cascade of positive therapeutic effects.

Phototherapy currently is being used in virtually every medical specialty including dermatology, plastic surgery, family medicine, vascular surgery, thoracic surgery, ophthalmology, ENT, gastroenterology, hematology, oncology, orthopedics, endocrinology, esthetics, urology, neurology, and neurosurgery to name a few. In general, phototherapy serves to improve wound healing, cellular function, reduction of edema, healing of neurological injuries, increased microcirculation and provides intrinsic pain relief.

More than 3,000 scientific references report restorative, therapeutic and healing result from the use of laser light. As with all kinds of scientific work, new discoveries generate new questions. In spite of tremendous advances in the scientific understanding of the medical effects of light we still do not know all the optimal parameters. However, we do know enough to make phototherapy a clinical treatment modality based upon evidence.

9467-21, Session 4

Van der Waals solids: materials properties, synthesis and device applications *(Invited Paper)*

Anupama B. Kaul, The Univ. of Texas at El Paso (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 van der Waals solids 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 novel properties of these layered 2D nanomaterials, including synthesis approaches for enabling their device applications in electronics, photonics and sensors.

9467-22, Session 4

Synthesis of Two Dimensional Materials for Beyond Graphene Devices *(Invited Paper)*

Kehao Zhang, The Pennsylvania State University (United States); Sarah Eichfeld, The Pennsylvania State Univ. (United States); Jacob Leach, Bob Metzger, Kyma Technologies (United States); Yu-Chaun Lin, The Pennsylvania State University (United States); Keith Evans, Kyma Technologies (United States); Joshua A. Robinson, The Pennsylvania State Univ. (United States)

The isolation of graphene constituted a new paradigm in next generation electronic technologies, and even though graphene is considered transformational, it is only the "tip of the iceberg." Transition metal dichalcogenides (TMDs) and their heterostructures could have an even greater impact on next generation technologies. Transition-metal dichalcogenides in the form of MeX2 (where Me = a transition metal such as Mo, W, Ti, Nb, etc. and X = S, Se, or Te) exhibit extreme flexibility, possession of tunable band gaps, modest electron mobilities, and wide variety of band-offsets. Synthesizing and heterogeneously combining these atomic layered TMDs to form van der Waals (vdW) solids, where each layer may be different from the previous, is a powerful way to develop novel nanoscale materials. Furthermore, having the ability to tune the physics and chemistry with atomic-level precision is the foundation for "properties-on-demand", which can have an enormous impact on current and future technologies. Furthermore, the development of devices from these novel layered materials could lead to new transport phenomenon and ultimately unique device arcitectures for next generation applications. This talk will elaborate on recent breakthroughs for direct growth of two-dimensional atomic heterostructures (MoS2, WSe2, and hBN) on a graphene template, and provide evidence that the direct growth of van der Waals solids could be key to realizing novel device arcitectures.

9467-23, Session 4

Synthesis, properties, and applications of group IV graphane analogues *(Invited Paper)*

Joshua Goldberger, The Ohio State Univ. (United States)

Similar to how carbon networks can be sculpted into low-dimensional allotropes such as fullerenes, nanotubes, and graphene with fundamentally different properties, it is possible to create similar "allotropes" of Si, Ge or Sn with unique optoelectronic properties as well. Here, we will describe our recent success in the creation of hydrogen and organic-terminated germanium graphane analogues, or germananes, from the topochemical deintercalation of CaGe2. We will discuss how the optical, electronic, and thermal properties of these materials can be controlled by substituting either the surface ligand or via alloying with other Group IV elements. Additionally, we have also developed an epitopotaxial approach for integrating precise thicknesses of Germanane layers onto Ge wafers that combines the epitaxial deposition of CaGe2 precursor phases with the topotactic interconversion into the 2D material. These materials represent a new class of covalently terminated graphane analogues and have great potential for a wide range of electronic, optoelectronic and sensing applications, especially since theory predicts these materials to have direct and tunable band gaps around 1.5 eV and electron mobilities that are around five times higher than that of bulk Ge.

9467-24, Session 4

Phase engineering in 2D materials *(Invited Paper)*

Manish Chhowalla, Rutgers, The State Univ. of New Jersey (United States)

Two-dimensional transition metal dichalcogenides (2D TMDs) — whose generalized formula is MX2, where M is a transition metal of groups 4–7 and X is a chalcogen — exhibit versatile chemistry and consist of a family of over 40 compounds that range from complex metals to semiconductors to insulator. Complex metal TMDs assume the 1T phase where the transition metal atom coordination is octahedral. The 2H phase is stable in semiconducting TMDs where the coordination of metal atoms is trigonal prismatic. We have been studying the 1T phase in semiconducting TMDs. In particular, we have focused on mechanisms involved in inducing the meta-stable 1T phase, kinetics of phase transformation and fundamental structural and electronic properties. We have implemented phase-engineered materials as hydrogen evolution reaction (HER) catalysts and as low resistance contact electrodes in electronic devices. We have also exploited the metallic nature of the 1T phase to functionalize a variety of TMDs. The attachment of functional groups leads to dramatic changes in the opto-electronic properties of the material.

9467-25, Session 4

Challenges and opportunities in 2D crystals: graphene and beyond *(Invited Paper)*

Huili G. Xing, Cornell Univ. (United States) and Univ. of Notre Dame (United States)

Two-dimensional (2D) crystals such as transition metal dichalcogenides (TMDs) along with other families of layered materials including graphene, SnSe2, GaSe, BN etc, has attracted intense attention from the scientific community. One monolayer of such materials represent the thinnest "quantum wells". These layered materials typically possess an in-plane hexagonal crystal structure, and can be stacked together by interlayer van der Waals interactions. Therefore, it is possible to create novel heterostructures by stacking materials with large lattice mismatches and different properties, for instance, superconductors (NbSe2), metals, semi-metals (graphene), semiconductors (MoS2) and insulators (BN). Numerous novel material properties and device concepts have been discovered, proposed and demonstrated lately. However, the low internal photoluminescence efficiency (IPE, < 1%) and low carrier mobility observed in the 2D semiconductors suggest strongly that the materials under investigation today most likely suffer from a high concentration of defects. In this talk, I will share our progress and the challenges we face in terms of preparing, characterizing these 2D crystals as well as pursuing their applications.

9467-26, Session 5

2D electronic materials for army applications *(Invited Paper)*

Terrance O'Regan, Philip Perconti, U.S. Army Research Lab. (United States)

The record electronic properties achieved in monolayer graphene and related 2D materials such as molybdenum disulfide and hexagonal boron nitride show promise for revolutionary high-speed and low-power electronic devices.

Heterogeneous 2D-stacked materials may create enabling technology for future communication and computation applications to meet soldier requirements.

For instance, transparent, flexible and even wearable systems may become feasible. With soldier and squad level electronic power demands increasing, the Army is committed to developing and harnessing graphene-like 2D materials for compact low size-weight-and-power-cost (SWAP-C) systems. This talk will review breakthrough developments in 2D electronic materials over the last five years and discuss directions for future army applications.

9467-27, Session 5

Two-dimensional materials synthesis and integration for low power and high frequency devices *(Invited Paper)*

Joshua A. Robinson, Suman Datta, The Pennsylvania State Univ. (United States)

In this work, I will discuss recent works in graphene and beyond for novel device applications. This includes a focus on epitaxial graphene materials and device properties, as well as "beyond graphene" opportunities that could lead to new areas of research. I will discuss how graphene nano-ribbon (GNR) devices can be utilized to achieve significantly improved RF ambipolar mixer performance compared to conventional sheet devices, leading to 20dB improved conversion gain at a channel length of 300nm. We study the effect of GNR geometries (50 - 100nm) on the charge transfer region (CTR) by analyzing changes in contact resistance, symmetry between p and n-branch, transconductance, and on-off ratio as a function of ribbon width. We experimentally demonstrate that GNR geometries can be utilized to reduce the impact of the CTR by enhancing the electrostatic coupling between gate and graphene channel through increased fringing fields, leading to improved transfer characteristics and p-n symmetry for highly scaled graphene devices. By reducing the impact of the CTR, RF GNR FETs are able to achieve 4.5x improved transconductance and 3x improved current gain cutoff frequency compared to sheet based devices as well as 4.9x improved symmetry between p and n-branch. Additionally, I will discuss the integration of epitaxial graphene with novel 2D materials such as molybdenum disulfide and tungsten diselenide and the existence of room temperature negative differential resistance in these material systems.

9467-28, Session 5

Increasing the lego of 2D electronics materials: silicene and germanene, graphene's new synthetic cousins *(Invited Paper)*

Guy Le Lay, Aix-Marseille Univ. (France)

The first synthesis of silicene, graphene's silicon based analogue, in 2012, has boosted research on two-dimensional materials beyond graphene, especially elemental synthetic ones. Two years after silicene, germanene, the germanium counterpart has been realized in 2014, while stanene (also coined tinene), the tin based cousin, is still awaiting for its creation. Silicene and germanene (as might be stanene/tinene) are novel Si and Ge (Sn) allotropes created under ultra-high vacuum conditions, which do not exist in nature, but which present similar electronic properties as those of graphene, but are 2D topological insulators at practicable temperatures. They possess the clear advantage of being directly compatible with the current nano/microelectronic technologies. Germanane, the fully hydrogenated germanene sibling, a direct band gap semiconductor, has been obtained by a wet chemistry procedure. Monolayer silicene must be encapsulated to be preserved in ambient air, while multi-layer silicene is self-protected by a very thin native oxide. This allows electrical measurements in air and prototypical device fabrication. In this invited talk I will present the state-of-the-art on these fascinating new 2D materials, their intriguing physical properties and their potential applications.

9467-29, Session 5

High-speed nanoelectronics based on graphene and beyond *(Invited Paper)*

Shu-Jen Han, IBM Thomas J. Watson Research Ctr. (United States)

Graphene has attracted much interest as a future channel material in high-frequency electronics because of its superior electrical properties. Recent development has been shifted from the device level study to the circuit level demonstration. I will review and discuss several key challenges for large-scale graphene device fabrication, including high quality gate dielectric, large-area film transfer, and output current saturation. Furthermore, fabrication of a graphene integrated circuit without significantly degrading transistor performance has proven to be challenging, posing one of the major bottlenecks to compete with existing technologies. I will review our effort of developing graphene IC in the past few years, starting with a simple 1-stage mixer built on a SiC piece, toward the recent demonstration of a high-performance three-stage graphene IC that fully preserves graphene transistor quality post-IC fabrication. This new circuit operates as a radio frequency receiver performing signal amplification, filtering and downconversion mixing. All circuit components are integrated into 0.6mm2 area and fabricated on 200mm Si wafers, showing the unprecedented graphene circuit complexity and silicon CMOS process compatibility. Beyond graphene, more suitable 2D materials with energy bandgap for electronics applications are being aggressively investigated. I will discuss some recent progress of transition metal dichalcogenides (TMDC) and black phosphorus (BP) based transistors in my group. In addition, other applications such as plasmonics and photodetectors using these novel 2D materials will be briefly discussed.

9467-30, Session 5

Graphene and beyond: two-dimensional materials for transistor applications *(Invited Paper)*

Frank Schwierz, Technische Univ. Ilmenau (Germany)

During the past few years, two-dimensional materials have found continuously increasing attention in the electronic device community. The first two-dimensional material studied in detail was graphene and many groups explored it as a material for transistors. During the early years of graphene research the expectations on its impact on future electronics have been extremely high. It soon turned out, however, that the missing bandgap of graphene causes serious problems for proper transistor operation. Therefore, meanwhile the prospects of graphene are assessed less optimistic.

Recently researchers have extended their work to two-dimensional materials beyond graphene and the number of two-dimensional materials under investigation is literally exploding. At present, several hundred of these materials are known, and part of them is considered to be useful for electronic applications. A realistic assessment of the prospects of the two-dimensional materials in electronics is, however, still missing. The present contribution represents is a step in this direction. After introducing the major classes of two-dimensional materials, we compose a wish list of material properties desirable transistor channels and examine to what extent the two-dimensional materials fulfill the criteria of our wish list. We review the current state-of-the-art of two-dimensional transistors, compare it to that of competing conventional transistors, and identify potential applications of two-dimensional materials and transistors. Finally, some of our own results on two-dimensional materials are presented.

9467-31, Session 5

2D materials for high-performance electronic, photonic and sensing applications *(Invited Paper)*

Steven J. Koester, Univ. of Minnesota, Twin Cities (United States)

Two-dimensional (2D) materials have been of tremendous interest in the last few years due to their novel electronic and photonic properties and their corresponding potential to realize a wide range of novel devices. In this talk, I will describe recent work on novel device applications of 2D materials for electronic, photonic and sensing applications. In particular, I will describe the potential of graphene as a high-Q variable capacitor for use in ultra-compact wireless sensors. Graphene also has enormous potential as a platform for integrated optoelectronics and I will detail theoretical and experimental results that show graphene can create high-speed optical modulators with extremely-low energy consumption. Furthermore, I will also demonstrate how heterostructures of 2D dichalcogenides can realize scalable transistors for ultra-low-power logic and memory applications. Finally, I will describe very recent results on black phosphorus that indicate extremely promising potential of this material for creating high-performance MOSFETs and photodetectors.

9467-32, Session 6

Nanotechnology meets biology in the cancer cell *(Invited Paper)*

Mostafa A. El-Sayed, Georgia Institute of Technology (United States)

A word about the reasons for the hype about nanotechnology will be given.1 Using the Plasmonic enhancement of Rayleigh scattering by silver or gold nanoparticles, we were able to image the behavior of communities of cancer cells as they are dying from increasing the concentration of the nanoparticles at their cell nuclei,2,3,4. In order to gain molecular information, we were able to record the time dependent enhanced molecular Raman vibration spectra (SERS) of the molecules anywhere in the cell during the full cell cycle from birth to division5 or if we give the cells cancer drugs, we can determine the time of the cell death. The potential future use of this new technique of "PLASMONIC ENHANCED MOLECULAR CELL IMMAGING (PEMCI)"in molecular cell biology and in medicine is pointed out.

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9467-33, Session 6

Superresolution imaging and SERS *(Invited Paper)*

Katherine A. Willets, The Univ. of Texas at Austin (United States) and Temple Univ. (United States)

Noble metal nanostructures are well-known for their ability to support localized surface plasmons, which lead to enhanced electromagnetic fields at the nanoparticle surface that are the basis for surface-enhanced spectroscopies, such as surface-enhanced Raman scattering (SERS). However, understanding the spectral coupling between molecular analytes and plasmonic nanostructures is complicated by the diffraction-limit of light, which prevents objects that are smaller than roughly half the wavelength of light from being resolved. This talk will describe using super-resolution SERS imaging to understand the coupling between single molecule analytes and plasmonic nanoparticles, with applications in imaging SERS “hot spots” and imaging electrochemical reactions on nanoparticle electrode surfaces.

9467-34, Session 6

Nanoplasmonic and metamaterials concepts for broadband surface enhanced sensing *(Invited Paper)*

Tyler R. Roschuk, Stefan A. Maier, Imperial College London (United Kingdom)

This presentation will present recent progress in surface enhanced sensing based on nanoplasmonic resonances. A particular focus will lie on surface structures allowing sensing in a broad window of the electromagnetic spectrum, encompassing the visible, near- and mid-infrared. Based on log period antennas, such a surface allows for simultaneous enhancement of fluorescence, Raman, and mid-IR absorption. The second part of the presentation will present a new scheme for surface enhanced sensing in the THz window, based on spoof surface plasmon polaritons.

9467-36, Session 6

A computational look at nano-scale toward giga-pixel nanoscopy *(Invited Paper)*

Aydogan Ozcan, Univ. of California, Los Angeles (United States)

My research focuses on the use of computation/algorithms to create new optical microscopy, sensing, and diagnostic techniques, significantly improving existing tools for probing micro- and nano-objects while also simplifying the designs of these analysis tools. In this presentation, I will introduce a new set of computational microscopes which use lens-free on-chip imaging to replace traditional lenses with holographic reconstruction algorithms. Basically, 3D images of specimens are reconstructed from their “shadows” providing considerably improved field-of-view (FOV) and depth-of-field, thus enabling large sample volumes to be rapidly imaged, even at nanoscale. These new computational microscopes routinely generate >1–2 billion pixels (giga-pixels), where even single viruses can be detected with a FOV that is >100 fold wider than other techniques. At the heart of this leapfrog performance lie self-assembled liquid nano-lenses that are computationally imaged on a chip. These self-assembled nano-lenses are stable for >1 hour at room temperature, and are composed of a biocompatible buffer that prevents nano-particle aggregation while also acting as a spatial “phase mask.” The field-of-view of these computational microscopes is equal to the active-area of the sensor-array, easily reaching, for example, >20 mm^2 or >10 cm^2 by employing state-of-the-art CMOS or CCD imaging chips, respectively.

In addition to this remarkable increase in throughput, another major benefit of this technology is that it lends itself to field-portable and cost-effective designs which easily integrate with smartphones to conduct giga-pixel tele-pathology and microscopy even in resource-poor and remote settings where traditional techniques are difficult to implement and sustain, thus opening the door to various telemedicine applications in global health. Some other examples of these smartphone-based biomedical tools that I will describe include imaging flow cytometers, immunochromatographic diagnostic test readers, bacteria/pathogen sensors, blood analyzers for complete blood count, and allergen detectors. Through the development of similar computational imagers, I will also report the discovery of new 3D swimming patterns observed in human and animal sperm. One of this newly discovered and extremely rare motion is in the form of “chiral ribbons” where the planar swings of the sperm head occur on an osculating plane creating in some cases a helical ribbon and in some others a twisted ribbon. Shedding light onto the statistics and biophysics of various micro-swimmers’ 3D motion, these results provide an important example of how biomedical imaging significantly benefits from emerging computational algorithms/theories, revolutionizing existing tools for observing various micro- and nano-scale phenomena in innovative, high-throughput, and yet cost-effective ways.

9467-37, Session 6

Opto-electro-mechanical biosensor enabled by graphene *(Invited Paper)*

Ertugrul Cubukcu, Alexander Y. Zhu, Fei Yi, Univ. of Pennsylvania (United States)

Graphene as a monolayer of carbon atoms in a honeycomb lattice has attracted significant interest for its unique optical, electrical, mechanical properties for a range of applications. Metal based plasmonic devices and sensors can capitalize on graphene for unprecedented new functionalities if synergistically integrated. One such intriguing property of graphene that plasmonics can benefit from is its impermeability to gas molecules even as small as a single He atom. Capitalizing on this we demonstrated that nanoantennas made of silver, the ideal plasmonic material that tends to oxidize due to sulfur containing ambient gases, can be effectively passivated with a monolayer graphene. Due to its atomic thickness, graphene also does not perturb nanoantenna near-fields significantly maintaining the full potential of silver nanoantennas in sensing applications.

Graphene is also a very promising material as a bioactive layer due to its ability to effectively adsorb biomolecules through pi-pi stacking interactions. If graphene is used as a monolayer functionalization layer, lengthy sensor surface modification steps will not be necessary. We studied the binding affinities between several different proteins and graphene and found that adsorption can be as strong as that of a specifically binding antigen-antibody pair.

We will also discuss a new multimodal opto-electro-mechanical device that synergistically combines a graphene field effect transistor based nanoelectronic sensor and a nanoantenna based photonic sensor on a mechanical resonator sensor. This hybrid approach combining electrochemical, refractive index, and mass sensing functions on the same device footprint opens up new directions in nano-bio-sensors with unprecedented features. This proof-of-concept nanosensor experimentally achieves sub-picomolar label-free detection limits across all three independent sensing modes, and possesses a dynamic range that is 2-3 orders of magnitude larger than that of any single mode nanosensor.

9467-38, Session 7

2D materials and heterostructures for applications in optoelectronics *(Invited Paper)*

Thomas Mueller, Technische Univ. Wien (Austria)

In this talk I will review our recent research activities on applications of two-dimensional (2D) materials and heterostructures in optoelectronics. In particular, I will present (i) a WSe2 monolayer p-n junction diode, formed by electrostatic doping using a pair of split gate electrodes, and (ii) a MoS2/WSe2 van der Waals type-II heterojunction. Upon optical illumination, conversion of light into electrical energy occurs in both devices. Biasing the p-n junctions in forward direction gives rise to light emission. We envision that the advantages of 2D materials, such as flexibility, high mechanical stability and low costs of production could lead to new photovoltaic solar cell and display technologies.

9467-39, Session 7

Plasmon excitations in low dimensional graphitic materials *(Invited Paper)*

Feng Wang, Univ. of California, Berkeley (United States)

Low dimensional graphitic materials like graphene monolayer and multilayers provide a unique system to explore plasmonics in the infrared and teratherz frequencies. In this talk, I will discuss our recent studies of tunable plasmonic excitation in such graphitic materials and their potential applications for nano photonics at infrared frequencies.

9467-40, Session 7

Optics and optoelectronics of 2D atomic membranes *(Invited Paper)*

Xiaobo Yin, Univ. of Colorado at Boulder (United States)

Integrated nanophotonics is already the strategic capability for industry and the key enabling technology for communication and information processing. To cope with the ever-increasing data traffic and capacity demands, novel and disruptive techniques are required, especially for the short-reach applications such as high performance computing and datacenters. Highly desirable are the devices that emit, modulate and detect multi-spectral signals with high-bandwidth and low-energy-consumption. Moreover, these devices shall allow efficient productions of densely packed photonic circuits that can be monolithically integrated with state-of-the-art semiconductor technologies. The rise of the pristine 2D materials, including graphene and gapped semiconducting TMDCs has been evident for the supreme properties and exceptional applications. In this talk we will discussion the ultrafast integrated graphene optical modulators, nonlinear optical devices enabled by TMDCs and new generation of light emitting and reciving devices that interface the spintronics and valleyoptoelectronics.

9467-41, Session 7

Graphene optoelectronic devices for optical communications and imaging *(Invited Paper)*

Dirk R. Englund, Ren-Jye Shiue, Massachusetts Institute of Technology (United States); Yuanda Gao, James Hone, Columbia Univ. (United States)

Graphene has many unusual optical and electrical properties that make it an attractive material for new types of opto-electronic devices. Here, we will describe recent progress on on-chip graphene optoelectronic devices, including high-speed modulators, photodetectors, and autocorrelators. By coupling graphene to an optical cavity, we demonstrated an efficient electro-optic modulator with a response speed exceeding 1 GHz. We also discuss silicon waveguide-integrated photodetectors that now achieve a responsivity in excess of 0.4 A/W and response in excess of 50 GHz. Autocorrelation measurements of such detectors indicate a bandwidth in excess of 100 GHz.

9467-42, Session 8

Origami: folding in nature, art and technology *(Invited Paper)*

Joycelyn S. Harrison, Air Force Office of Scientific Research (United States)

Origami is typically valued for its artistic complexity and beauty but the prevalence of origami forms in nature and in inspiring technology suggest that this traditional Japanese paper folding technique has value that transcends art. The appeal of origami and programmed folding is its simplicity, versatility, and ability to employ existing 2D patterning techniques (e.g., screen printing, lithography) to convert surface patterns on substrates into stable 3D structures within seconds upon exposure to appropriate stimuli (e.g. light, heat, electric field). Joint investments by the National Science Foundation and the Air Force Office of Scientific Research in a 2011 Emerging Frontiers in Research and Innovation Initiative have stimulated broad-spectrum research exploring folding and unfolding of materials and structures at all scales (i.e. nano to macro) and across scales to create novel designs, mechanisms, structures and devices. Much of this research has focused on developing enabling materials, physic-based methodologies and mathematical rigor to broaden the underlying science and applicability of origami. This presentation will highlight recent advances in the application of origami concepts in spurring new multidisciplinary scientific discovery and provide perspectives on the value of exploring an ancient art-form to invigorate novel, transformative research with far-reaching applications.

9467-43, Session 8

Bringing physics into the fold: Origami-inspired mechanical meta-materials *(Invited Paper)*

Itai Cohen, Cornell Univ. (United States)

Tessellated patterns, realistic animals, and curved polygonal shapes are all examples of the beautiful and amazing sculptures that can now be made using Origami, the art of paper folding. This art form has experienced tremendous growth with the advent of mathematical techniques that allow the basic structure of any new sculpture to be plotted out before any folding occurs, and laser cutter technologies that have made it easier to create folds in a variety of materials. In addition to their static properties, Origami sculptures can be designed to have a wide variety of mechanical properties making them responsive and tunable. In this talk I will describe our efforts to bring together artists, materials scientists, engineers, mathematicians, and yes, physicists to make meta-materials base on origami principles. Our teams are interested in making structures with a broad range properties including, tunable mechanical stiffness, mechanical cloaking capabilities, and topological constraints that can be utilized to design switches. The materials we work with range from paper models, to thermally responsive gel sheets, and even graphene. Collectively, we strive to design material platforms that can be used as building blocks for the nano and micro scale mechanical devices of the future.

9467-44, Session 8

Design tools for adaptive Origami devices *(Invited Paper)*

Philip Buskohl, Kazuko Fuchi, James J. Joo, Greg W. Reich, Richard Vaia, Air Force Research Lab. (United States)

Origami structures morph between 2D and 3D conformations along predetermined fold lines that efficiently program the form, function and mobility of the structure. The transfer of origami concepts to engineering design shows potential for many applications including solar array packaging, tunable antennae, and deployable sensing platforms. However, the enormity of the design space and the complex relationship between origami-based geometries and engineering metrics places a severe limitation on design strategies based on intuition. This motivates the development of design tools based on optimization to identify optimal fold patterns for geometric and functional objectives. The present work proposes a topology optimization method, using truss and frame element analysis, to distribute foldline properties within a reference crease pattern. By removing unnecessary folds, an optimal topology for a specific motion, stress level, or energy distribution can be determined. The optimizer results include the recreation of known action origami structures and the Miura-Ori, as well as new asymmetric actuator designs. This design suite offers an important step toward systematic incorporation of origami design concepts into new, novel and reconfigurable engineering devices.

9467-45, Session 8

A novel reconfigurable Origami spiral antenna utilizing 3D printing technologies *(Invited Paper)*

Manos M. Tentzeris, Christy Saintsing, Georgia Institute of Technology (United States)

A reconfigurable origami-based Archimedean spiral antenna was created using an additive manufacturing process. In its planar configuration, the spiral antenna possesses a bidirectional pattern, which becomes more directive as the antenna is telescoped to its conical form, thereby exhibiting higher gain. The Japanese art of origami was the inspiration for this telescoping feature. Recently there has been much interest in deployable origami, which is folded in a manner that allows compression and expansion of an object. For example, a conical structure can undergo a transition to a flat state by pushing the ends together and then expand back to its original shape by pulling the ends apart. It has to be stressed that this work relies on the thermal properties of 3D printed shape memory polymers to achieve a partially self-actuating "origami- type" telescoping action. An Objet Connex 260 multi-material polymer printer was used to create the substrate for the antenna. Tango Plus Black and Vero White were the inks used in this work. The thermomechanical properties of the matrix can be controlled by adjusting the ingredient ratio of the polymer ink. A printed prototype of the substrate in planar form is shown in Figure 1. By exceeding the glass transition temperature, the structure can be telescoped and cooled to maintain a variety of lengths as shown in Figure 2 and Figure 3. The planar shape can be retrieved by repeating the above procedure and applying a small force while cooled.

9467-46, Session 8

popupCAD: a tool for automated design, fabrication, and analysis of laminate micro-devices *(Invited Paper)*

Daniel M. Aukes, Robert J. Wood, Harvard Univ. (United States) and Wyss Institute for Biologically Inspired Engineering (United States)

Recent advances in laminate manufacturing techniques have driven the development of new classes of millimeter-scale sensorized medical devices, robots capable of terrestrial locomotion and sustained flight, and new techniques for sensing and actuation. These devices are built upon the principles of iterative additive and removal manufacturing techniques which encode a high degree of mechanical precision in two-dimensional laminate structures, which can then be used both during assembly and operation to create complex, user-specified motion paths. This motion is rather inexpensive to vary, as the patterns of material retained and removed in the laminate which determine this motion can be changed part to part within the same production run to create mass-customizable devices suited for a particular need, or to quickly converge on a useful set of design parameters.

The development of these devices has been facilitated by a new design tool called popupCAD, which seeks to automate the tasks associated with manufacturing, from generating support geometry, analyzing manufacturability, removing scrap, and producing cut files. This is further facilitated through the use of inherently-manufacturable design techniques such as composition from existing libraries of manufacturable parts and design for flat-foldability. These techniques have been implemented on new devices such as a modular hexapod walking robot called "printapede", which has been designed to reduce the number of manual assembly steps used in current designs.

So far, however, the analysis of laminate micro-devices has focused on manufacturability concerns and not on performance issues. Considering the nature of such devices, we draw from existing research in composites, origami kinematics, and finite element methods in order to identify issues related to sequential assembly and self-folding prior to fabrication as well as the stiffness of composite folded systems during operation. These techniques can be useful for understanding how such devices will bend and flex under normal operating conditions, and when added to popupCAD, will give designers another means to develop better devices throughout the design process.

9467-47, Session 8

HanaFlex: A Large Solar Array for Space Applications *(Invited Paper)*

Shannon A. Zirbel, Brigham Young Univ. (United States); Brian P. Trease, Jet Propulsion Lab. (United States); Mark W. Thomson, NASA Jet Propulsion Laboratory (United States); Robert J. Lang, Lang Origami (United States); Spencer P. Magleby, Larry L. Howell, Brigham Young Univ. (United States)

Compliant mechanisms rely on the deflection of flexible members for mobility rather than using traditional joints such as hinges or bearings. Advantages of compliant mechanisms include dramatic reduction in the total number of parts required to accomplish a specified task, significant reduction in weight over their rigid-body counterparts, and the ease in which they are miniaturized. This presents opportunities to replace complex parts of multiple materials with simplified, fewer parts that deliver equivalent mechanics. For centuries origami artists have been developing compliant mechanisms in paper. They have invested immeasurable effort developing origami under extreme self-imposed constraints (e.g. only paper, no cutting or gluing, one regular-shaped sheet). The accessible and formable medium of paper has enabled swift prototyping of vast numbers of possible designs. This has resulted in stunning origami structures and mechanisms that were created in a simple medium and using a single fabrication process (folding). The origami artists' methods and perspectives have created compliant mechanisms that have not previously been conceived using traditional engineering methods. Using origami-inspired methods, it may be possible to design origami-like systems, but using different materials and processes to meet emerging product requirements. The ability to start with a flat sheet and morph into other shapes offers unique opportunities for deployable systems, particularly in space applications. This presentation will review the connection between origami and compliant mechanisms, and discuss applications in space systems, including a deployable solar panel and 3D printed titanium positioning

mechanisms. The current state of the field and areas of future research will also be addressed.

9467-48, Session 9

Industry-first field trial of inter-well reservoir nanoagent tracers *(Invited Paper)*

Mazen Kanj, Saudi Aramco (Saudi Arabia)

This talk highlights the industry's first proven reservoir nanoagent design and demonstrates a successful multi-well field trial using these agents. This fundamental tracer template is intentionally geared towards the harsh but prolific ARAB-D carbonate reservoir environment of 100+?C temperature, 150,000+ppm salinity, and an abundant presence of divalent ions in the connate water. Preliminary analyses confirmed nanoparticles' breakthrough at a producer nearly 500m from the injector at the reservoir level; thus, proving the tracer nanoparticles' mobility and transport capability. This is considered industry-first and a breakthrough achievement complementing earlier accomplishments in regard to the nanoagents' reservoir stability with the first successful single well test and ease of scale up with the synthesis of one metric ton of this material. The importance of this accomplishment is not in how sophisticated is the sensing functionalities of this design but rather in its stability, mobility, scalability, and field application potentials. This renders the concept of having active, reactive, and even communicative, in-situ reservoir nanoagents for underground sensing and intervention a well anticipated near-future reality.

9467-49, Session 9

Application of nanotechnology to drilling fluids: How close are we? *(Invited Paper)*

James E. Friedheim, M-I SWACO (United States)

Nanotechnology has been successfully applied in a variety of areas including electronics, material composites, medical applications, and consumer goods. It is only natural that the utility of nanotechnology from these fields is transferred to the oilfield. Universities and consortiums have made efforts to apply nanotechnology (e.g., nanosensors, nanomarkers, and the more esoteric nanobots) to gathering valuable data from the reservoir. This research is of great importance due to the potentially large return on investment, but has yet to produce any substantive products. By contrast, research of nanotechnology for drilling applications, such as drilling fluids, is lesser known, even though numerous companies have invested a considerable amount of time and money. These companies are now beginning to realize both positive results and commercial products.

The traditional research and development projects continue in the areas of shale inhibition, rheology modification, wellbore strengthening, and high-pressure, high-temperature drilling fluids. This paper will, however, review recent works on the application of nanotechnology and further address some of the perceived concerns (real or not) of sourcing and using commercial "nano" products. Additionally, the paper will include a review of current health, safety and environmental (HS&E) perspectives on this new area of oilfield chemistry.

9467-50, Session 9

Autonomous micro and nano sensors for upstream oil and gas *(Invited Paper)*

David Chapman, The Univ. of Texas at Austin (United States); Walter J. Trybula, The Trybula Foundation, Inc. (United States)

This paper describes the development of autonomous micro and nano-scale sensor systems for very harsh downhole oilfield conditions and provides an overview the operational requirements necessary to survive and make direct measurement of subsurface conditions. One of several significant developmental challenges is selecting appropriate technologies that are simultaneously harsh environment capable, miniaturize-able, and integrate-able, while still operationally valuable for specific oil and gas applications. The Advanced Energy Consortium (AEC) is employing a platform approach to testing multi-chip, micron scale, systems in a package at elevated temperature and pressure in API brine and oil analogs, with the future goal of autonomous, downhole, and submicron systems on a chip, that enable the collection of previously unattainable data. The goal is to develop subsurface nanosensors that can be injected into oil and gas well bores to gather and report data, providing an unparalleled level of reservoir characterization. This paper provides a status update on the research efforts and developmental successes at the AEC from 2009-2013.

9467-51, Session 9

CMOS methods for the creation of novel sensors for down-hole and surface applications *(Invited Paper)*

Sameer Walavalkar, Chieh-Feng Chang, Axel Scherer, California Institute of Technology (United States)

Creating CMOS sensors for oil and gas applications requires the development of application specific fabrication and design. Unlike for most sensors, the material, temperature, and pressure demands for surface or down-hole sample examination are uniquely stringent. For example, when performing down-well ion-sensing the high-temperature (>125 oC) and corrosive environment literally dissolves silicon and standard metallic contacts. Fortunately, our research group has a tradition of creating novel fabrication techniques for unique applications, including: self-terminating oxidation for silicon luminescence and silicon-only heterostructures for quantum behavior. Using some of these methods we have been able to fundamentally alter the physical and electronic properties of silicon in ways that can make it an appropriate material choice for the unique requirements of oil and gas sensors. This presentation will cover the methods of fabrication and design we have used to address these requirements on a case by case basis. Techniques of note include ambipolar, dopant free devices; full dielectric encapsulation; membrane based hollow gate transistors; metallic reflow procedures, and all metal devices. We will cover the fabrication and operation of: Down-hole ion-sensors, field-based ion discriminators, diffusion sensors for spatially resolved sensitivity, channel free electronics, and optical devices for down-hole Raman measurements.

9467-52, Session 9

Diamond photonics: towards sensing applications in harsh environments *(Invited Paper)*

Marko Loncar, Harvard School of Engineering and Applied Sciences (United States)

Diamond possesses remarkable physical and chemical properties, and in many ways is the ultimate engineering material. For example, diamond is transparent from the ultra-violet to infra-red, has a high refractive index (n = 2.4), strong optical nonlinearity (Kerr and Raman) and a wide variety of light-emitting defects. These properties make diamond a highly desirable material for many applications, including quantum optics, nonlinear optics, magnetic and electric field sensing, and NEMS.

I will review advances in nanotechnology that have enabled fabrication of nanoscale optical and mechanical devices in diamond. Examples include diamond nanowires and plasmonic cavities, ring and photonic crystal resonators, and cantilevers. As an example application, I will review our work on diamond based on-chip frequency combs and possible applications in spectroscopy over broad wavelength range (from UV to infrared).

9467-53, Session 10

Functional sensor material enabled harsh environment, high temperature optical sensors for energy applications *(Invited Paper)*

Paul R. Ohodnicki Jr., National Energy Technology Lab. (United States)

Opportunities exist for increasing efficiency of utility scale fossil-based power generation systems and enabling adoption of new technologies through sensors and controls that would allow for embedded sensing at the highest value locations. Relevant technologies include advanced boilers, oxy-fuel combustion systems, gas turbines, gasifiers, and solid oxide fuel cells, all of which involve extremely high temperatures and reducing, oxidizing, and/or corrosive environments. Similar needs can be identified in a broad range of other applications and industries including aerospace, aviation, automotive, and manufacturing processes for semiconductors, metals, glass, and chemicals. A number of sensor technologies are currently under development for applications in such extreme high temperature and harsh environment conditions including chemi-resistive, electrochemical, and surface acoustic wave based devices. Optical based sensors are also under development and they are known to display a number of unique and inherent advantages which include: (1) the lack of electrical wiring or connections at the sensing location, (2) compatibility with broadband wavelength and distributed interrogation, and (3) the elimination of potential safety hazards associated with electrical sparks when deployed in flammable atmospheres.

Advanced functional sensor materials can play an important role in enabling new sensor devices of all types with unique functionality and improved stability in harsh operating conditions. In support of this need, the in-house research team at the National Energy Technology Laboratory (NETL) has recently established an advanced sensor material program focused on research and development of new sensing materials in parallel with demonstration on fabricated sensors under relevant high temperature conditions. The research program has placed a particular emphasis on understanding optical responses of materials to parameters of interest under relevant high temperature testing conditions. A brief overview of the program and research team capabilities will be presented and placed in the context of the larger sensors and controls program managed by the NETL. Recent breakthroughs of the on-going research and development efforts of the in-house research team will also be discussed.

9467-54, Session 10

Ultra-high temperature fiber optical chemical sensors based on nano-porous metal oxides *(Invited Paper)*

Kevin P. Chen, Univ. of Pittsburgh (United States)

This paper presents fiber optical gas sensors based on nano-porous metal oxide functional materials for high-temperature energy applications. A solution-based scalable nano-manufacturing approach was used to produce nano-porous functional metal oxide and their dopant variants using a block-copolymer templating approach. The refractive index of the film was tailored to adapt the optical fiber material by 3D nanostructuring in the sub-wavelength regime (20 nm or less). Using this nanomanufacturing scheme, this paper reports synthesis of nanoporous palladium (Pd) doped titanium dioxide (TiO2) film and its integration on D-shaped fiber Bragg grating (FBG) and sapphire fiber for hydrogen sensing at extremely high temperature up to 800C.

Through the control of porosity of TiO2 film, the refractive indices of Pd-doped TiO2 films were lowered to 1.44 for on fiber integration. The sensor is based on the refractive index changes and optical loss through evanescent field interaction in hydrogen sensitive metal oxide cladding. The flat side of D-shaped fiber grating was etched to remove a residual 4micron-meter cladding material, and thermally stabilized at 700C for high temperature applications. Using the chemical regenerative approach, high-temperature stable FBG were inscribed in D-shaped fiber. The FBGs in sapphire fibers were fabricated using the ultrafast laser direct writing scheme. The Bragg grating peaks were used to monitor the refractive index change and optical absorption loss due to the redox reaction between Pd-doped TiO2 sensing films and hydrogen from the room temperature to 800C. The fiber sensor responses were measured with various hydrogen concentration from 0.1 vol. % to 5 vol. % hydrogen in hydrogen/nitrogen gas mixtures. The experimental result shows the sensor's hydrogen response is reversible. The response time of the hydrogen sensor is less than 8 seconds. The applications of these high-temperature hydrogen sensors for energy applications such as solid oxide fuel cells are discussed.

9467-55, Session 10

Phosphor-based fiber optic temperature sensors for harsh environments *(Invited Paper)*

Nicholas Djeu, Yutaka Shimoji, MicroMaterials, Inc. (United States)

Fiber optic temperature sensors based on Yb doped phosphors will be described. Ytterbium in its trivalent form is unique among rare earth ions because of its simple energy level structure with just a single excited electronic state, which lies approximately 10,000 cm-1 above the ground state. This large energy separation leads to a situation where the multiphonon relaxation rate of the excited state at even extremely high temperatures can be readily measured. Then, by correlating the decay rate of the excited state with the temperature, a useful temperature sensor can be implemented. With the use of a moderate-power diode laser as the excitation source, temperature sensors of this type operating up to 1,600 C have been demonstrated.

We have thus far focused on YAG as the host material for the Yb ions. In our early work, the Yb doped YAG phosphor was grown directly onto one end of a single -crystal undoped YAG fiber using the laser heated pedestal growth technique. In order to reduce the fabrication cost, we have recently investigated the feasibility of incorporating the phosphor into the fiber optic thermal probe in the form of a microsphere. The lensing effect produced by the microsphere focuses the excitation light that emerges from the lead fiber into the phosphor as well as the induced fluorescence back into the fiber. As a result, sufficient signal can be obtained even from microspheres with diameters much less than 1 mm. With such a construction, sensors with a maximum operating temperature of 1,100 C have been demonstrated using an LED as the excitation source.

9467-56, Session 10

Development of Laser induced breakdown spectroscopy (LIBS) sensor to assess groundwater quality impacts *(Invited Paper)*

Cantwell Carson, National Energy Technology Lab. (United States); Christian Goueguel, USDOE National Energy Technology Laboratory (United States); Jinesh Jain, Dustin McIntyre, National Energy Technology Lab. (United States)

The injection of CO2 into deep aquifers has the potential to affect the quality of groundwater supplies if leakage were to occur by adding contamination from the injection formation or fluids. Therefore, the detection of CO2 and/or entrained contaminants that migrate into shallow groundwater aquifers is important both to assess storage permanence and to evaluate impacts on water resources. Naturally occurring elements (i.e., Li, Sr) in conjunction with isotope ratios can be used to detect such leakage. We propose the use of laser induced breakdown spectroscopy

(LIBS) as an analytical technique to detect a suite of elements in water samples. LIBS has a real time monitoring capability and can be applied for elemental and isotopic analysis of solid, liquid, and gas samples. The flexibility of probe design and use of fiber optics make it a suitable technique for real time measurements in harsh conditions and in hard to reach places. The laboratory scale experiments to measure Li, K, Ca, and Sr composition of water samples indicate that the technique produces rapid and reliable data. Since CO2 leak from saline aquifers may accompany brine solution we studied the effect of sodium salts on the accuracy of LIBS analysis. In addition to ground water, the applicability of the technique to issues with injection well leakage, monitoring wells, abandoned well location and monitoring, location and mitigation of improperly completed wells in the basin as well as bore holes with failed seals and wells will be discussed. This work specifically details the fabrication and application of a miniature ruggedized remotely operated diode pumped solid state passively Q-switched laser system for use as the plasma excitation source for a real time LIBS analysis. This work also proposes the optical distribution of many laser spark sources across a wide area for widespread leak detection and basin monitoring.

9467-57, Session 10

Temperature dependence of hydrogen related absorption in silica glass optical fibers at high temperatures *(Invited Paper)*

Elizabeth A. Bonnell, Li Yu, Daniel Homa, Virginia Tech Ctr. for Photonics Technology (United States)

This study reports on the behavior of silica based optical fibers in a hydrogen environment at high temperatures. The hydrogen response in the form of optical loss in the wavelength range of 1000-2500 nm of three different 50/125 mulitmode fibers was examined in the temperature range of 20-800 °C. The three fibers studied included two pure silica core step index fibers, one with high OH content, one with low OH content, and one germanium doped core graded index fiber. Two hydrogen-related infrared absorption bands were observed: ~2200 nm assigned to the combination vibration mode of Si-OH bending and the fundamental hydroxyl stretching mode and ~1390 nm assigned to the first overtone of the hydroxyl stretch. With increasing temperature the absorption in the 2200 nm band decreased in intensity while the absorption in the 1390 nm band shifted to longer wavelengths. This temperature dependent behavior was reversible with the spectrum returning to its initial position when temperature was decreased. The observed temperature dependent behavior is believed to be due to a change in the number of silanol groups participating in hydrogen bonding such that at higher temperatures more silanol groups participate in hydrogen bonding.

9467-59, Session 11

A control theoretic approach to neuromorphic computing *(Invited Paper)*

Michael Dorothy, Univ. of Illinois at Urbana-Champaign (United States)

We developed a simplified PD-like controller created with a spike-bursting neural network. We selected Izhikevich's neuron model and Rabinovich's synapse model so that they could be implemented in hardware and to preserve the potential for behaviorally complex computing with networks of neurons. Two simple classical control-like networks were devised which could interact with traditional robotic devices and control a simple pendulum system. Results are given in simulation, showing the potential for PD-like control from a minimal two-neuron network.

9467-60, Session 11

Bio-inspired sensing and control for disturbance rejection and stabilization *(Invited Paper)*

Gregory Gremillion, James S. Humbert, Univ. of Maryland, College Park (United States)

The successful operation of small unmanned aircraft systems (sUAS) in unknown, dynamic environments demands robust stability in the presence of exogenous disturbances. Traditionally, a minimal set of inertial sensors approximately collocated at the vehicle center of mass is used for stabilizing control of aircraft of varying scales. Using this sensing architecture to directly estimate the forces and torques applied to an airframe can be challenging in free flight. Direct sensing of the forces and torques applied to the vehicle airframe, either by actuators or external inputs, can be used for stability and control augmentation to produce a more robust platform with improved reference tracking and disturbance rejection. Flying insects are characteristically sensor-rich platforms, with multi-modal and highly redundant arrays of sensors, some sensitive to inertial states. The integration of sensory inputs across the insect body yields diminished noise in state estimates and encodes greater state information than could be possible with any single sensor. This work presents a novel sensing framework in which a redundant array of accelerometers distributed away from the vehicle center of mass is used to directly estimate the total forces and torques applied to a rigid airframe. Distributing the sensors away from the center of mass encodes a larger set of state information in the form of translational, Coriolis, Euler, and centripetal acceleration states, which directly relate to applied forces and torques. Measurements from the array of accelerometers are linearly combined, given knowledge of their position within the body-fixed reference frame, to estimate the full 6 degree-of-freedom force and torque vector. As in the insect sensory system, this wide-field sensing method provides improvements in signal-to-noise ratio when compared to a smaller or minimal subset of sensors. Furthermore, this linear estimation scheme lends itself to an analog-VLSI implementation, which is maximally scalable to sUAS and produces estimates at extremely high bandwidths. The force and torque vector is estimated with this novel sensor array for a simulated vehicle for various flight conditions. The estimation performance of the sensing mechanism is characterized via simulation. Estimate accuracy is quantified as a function of sensor noise level, position estimate error, and sensor quantity. Analytical constraints on sensor placement is also detailed.

9467-61, Session 11

High-speed autonomous navigation of unknown environments using learned probabilities of collision *(Invited Paper)*

Charles Richter, Nicholas Roy, Massachusetts Institute of Technology (United States)

We present a motion planning algorithm for dynamic vehicles navigating through unknown environments. We focus on the scenario in which a fast-moving car attempts to navigate from a start location to a set of goal coordinates in minimum time with no prior information about the environment, building a map in real time from on-board sensor data. Whereas existing planners for exploration confine themselves to a conservative set of constraints to guarantee safety around unknown regions of the environment, we instead learn a hazard function from data, which maps the vehicle's dynamic state and current environment knowledge to a probability of collision. We perform receding horizon planning in which the objective function is evaluated in expectation over those learned probabilities of collision. Our algorithm demonstrates sensible emergent behaviors, like swinging wide around blind corners, slowing down near the map frontier, and accelerating in regions of high visibility. Our algorithm is capable of navigating from start to goal more quickly than the conservative baseline planner without sacrificing safety. We demonstrate our algorithm on a 1:8-scale RC car equipped with a planar laser range-finder and inertial

measurement unit, reaching speeds of 4m/s in unknown, indoor spaces. A video of experimental results is available at: http://groups.csail.mit.edu/rrg/nav_learned_prob_collision.

9467-62, Session 11

Characterization of small field anomaly detection from optic flow *(Invited Paper)*

Gregory Gremillion, Univ. of Maryland, College Park (United States); Joseph K. Conroy, Allison M. Mathis, William D. Nothwang, U.S. Army Research Lab. (United States)

Previous implementations of wide field integration (WFI) of optic flow for reactive obstacle avoidance have focused on detection of low spatial frequency objects for navigation in corridor-like environments. Conversely, robust detection of small field obstacles is a missing, but necessary capability for reliable obstacle avoidance in the real-world environment. We propose to characterize and quantify the efficacy of small object and anomaly detection as a function of imager characteristics, optic flow computation properties, and the spatio-temporal characteristics of the visual anomaly. To this end, we simulate wide field optic flow patterns on an imaging surface with precise control of simulated small field anomalies to determine empirical thresholds for successful object detection. Validation of these simulation results is performed in a 2-D optic flow hardware implementation.

9467-63, Session 12

Dynamic legged locomotion for palm-size robots *(Invited Paper)*

Ronald Fearing, Duncan Haldane, Univ. of California, Berkeley (United States); David Zarrouk, Ben-Gurion Univ. of the Negev (Israel)

Minimally-actuated palm-size robots are capable of running at speeds greater than 2 meters per second (20 body lengths per second), with leg stride rates of greater than 20 Hz. In this dynamic regime, passive stabilization is needed for roll-and-pitch instability.

However, we have found that certain roll-oscillation modes can be used for high speed turning. Other turning modes have also been identified, such as modulating foot contact location through foot compliance. Interestingly, palm-size legged robots are approximately as efficient as their larger counterparts, and the simpler designs lend themselves to more direct measurements of energy for cost-of-transport estimates.

The VelociRoACH [1] is a 10 cm long, 30 gram hexapedal millirobot capable of running at 2.7 m/s, making it the fastest legged robot built to date, relative to scale. By implementing an aerodynamic rotational damper, we further reduced the rotational energy in the system, and demonstrated that stable limit cycles with lower rotational energy are more robust to disturbances. This method increased the stability of the system without detracting from forward speed.

We analyzed the dynamic turning motion of both VelociRoACH, a C-shape legged robot [2], and STAR, a single actuator hexapedal "whegs-style" robot [3,4]. For VelociRoACH, we explored a family of phase locked turning gaits where all legs of the robot move at the same speed [2]. These gaits are highly periodic, allowing the vertical height and roll angle of the robot to be approximated by single harmonic sinusoidal functions. We demonstrated that oscillations in height and roll angle determine the robot's turning behavior, and obtained a new high speed turning gait (forward velocity: 0.4 m/s, turn rate 200 degrees per second).

For STAR, we found a novel dynamic gait to control in-plane locomotion [3] (forward, back, clockwise and counter clockwise rotations) of a compliant legged hexapedal robot using a single actuator. The gait exploits the compliance disparity between alternate stance tripods, to generate rotation by controlling the acceleration of the robot. We analyzed the cost of transport of STAR [4]including energy consumption in sliding, work against gravity, elastic losses of the legs and the surface, and kinetic energy and compare them to the total energy input of the actuators. We found that at a slope of 0.3, cost-of-climbing is just 2.

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9467-64, Session 12

Metastable legged locomotion in real-world environments: methods to quantify and optimize reliability *(Invited Paper)*

Katie Byl, Cenk O. Saglam, Univ. of California, Santa Barbara (United States)

Legged systems are developed to fill a niche in which they can outperform wheeled locomotion in providing robust mobility in real-world environments. As such, reliable performance on stochastic terrain is a critical goal. In this work, we provide an intuitive overview of methods we have developed in recent years to capture the dynamics of a high-dimensional legged system using an approximately 2D mesh. This tractable mesh can then be used to optimize control at two distinct levels, (1) selecting low-level gait parameters for each of a family of distinct walking gaits, and (2) deriving optimal switching policies, based on noisy sensing of internal states and upcoming terrain. Resulting walking on rough terrain is well-described as being metastable, i.e., it exhibits very long periods of near-limit-cycle behavior but is also guaranteed to eventually fall down for non-trivial levels of terrain variability.

Although our tools have been specifically developed to analyze a planar model of an underactuated, point-foot walker, they are also applicable across a wide variety of other complex dynamic systems in which the long-term (mixing) effects of stochasticity are hard to predict and where guarantees of absolute reliability are not possible. Our presentation highlights several specific results, toward emphasizing the magnitude of improvement one can achieve in system reliability, while simultaneously focusing on an intuitive, tutorial explanation of the basic modeling steps required, toward encouraging and enabling adoption of these techniques in benchmarking and subsequently optimizing a variety of other system, with an emphasis on legged robots.

Our particular results focus on presentation of two low-level gait controllers, each of which is provably stable on constant-slope terrain. Using our mesh-based techniques, we optimize parameters defining each low-level gait in order to maximize the average steps-to-failure. This optimization can also include secondary goals, such as improved energy efficiency and/or maximizing speed, thus achieving significant improvements in these secondary aspects with only minor reductions in reliability. More importantly, the method provides an apples-to-apples metric that researchers can use to compare any of a variety of competing gait control strategies in a quantifiable way.

At a higher level, we also demonstrate how to develop control policies to switch among low-level controller to further improve reliability and to allow for foothold selection based on noisy information about upcoming terrain profile. We discuss the issue of modeling error and estimate the magnitude of error created by using our meshing approximation. For example, we demonstrate that results converge numerically as the mesh increases in resolution.

Our most significant goal in this paper is to emphasize the fact that resulting

performance frequently varies by many orders of magnitude (e.g., millions vs thousands of steps between failures) between competing low-level strategies that both generate stable limit cycle with seemingly similar energetic and speed properties, on identical dynamic robot models. Our work presents a tutorial guide to allow other researchers to adopt our methods to benchmark and improve a variety of other complex dynamic systems in which reliability is essential.

9467-65, Session 12

SCATTER reveals a superposition principle of robot locomotion on heterogeneous terrain *(Invited Paper)*

Feifei Qian, Daniel I. Goldman, Georgia Institute of Technology (United States)

Many flowable substrates are composed of particulates of varying size, from fine sand to pebbles and boulders. Ambulatory locomotion on such heterogeneous substrates is complicated in part due to fluctuations introduced by heterogeneities. To systematically explore how heterogeneity affects legged locomotion, we study the locomotion trajectory of a 6-legged robot (Xplorerbot, 15 cm, 150 g, using an alternating tripod gait) in a trackway filled with ~1 mm poppy seeds (the sand), and an embedded ~5 cm "boulder" whose shape we systematically varying by 3D printing different regular polyhedra. We investigate how the presence of the boulder affects trajectories using our automated "Systematic Creation of Arbitrary Terrain and Testing of Exploratory Robots" (SCATTER) system. The robot trajectory is straight before boulder interaction, and is scattered to an angle after the interaction. This angle can sensitively depend on the leg-boulder contact position (contact zone) and the boulder mobility within the fine sand. However, the scattering pattern dependence upon limb contact zone on the boulder is insensitive to boulder shape and roughness. Analysis of the robot trajectory indicates that the existence of a single boulder can be modeled using a scattering potential with attractive and repulsive features. Using this universal scattering rule as a prior knowledge, the robot is able to perform anticipatory feedback control using a swing-insertion tail, reducing the average scattering angle to 0.38°.

9467-66, Session 12

Data driven models of legged locomotion *(Invited Paper)*

Shai Revzen, Univ. of Michigan (United States)

Legged locomotion is a challenging regime both for experimental analysis and for robot design. In biology we know that most rapid locomotion in legged animals is achieved by using regular, nearly periodic leg motions. Dynamical systems with a stable limit cycle that are subject to substantial drift in phase are sometimes called "rhythmic" systems.

We present Data Driven Floquet Analysis (DDFA), a technique for using observed trajectories of a rhythmic system for reconstructing both the limit cycle and the dynamics which bring perturbed states back to it. We apply DDFA to legged locomotion systems and present within this mathematical framework several recent developments regarding systems with discontinuities in the equations of motion ("hybrid" systems) such as appear when feet contact the ground. We also present empirical tools for the characterization of leg synchronization and gait transitions, and motivate their use with examples and proofs. Taken together these results provide both a general picture of the dynamics achievable by legged systems, and a rich collection of tools for their empirical characterization.

9467-121, Session 12

Bio-inspired principles of terrestrial motion sciene

Robert J. Full, Univ. of California, Berkeley (United States)

Biological Inspiration is the use of principles and analogies from biology when advantageous to generate novel designs through integration with the best human engineering. Now more than ever before, nature can instruct us on how to best use new materials and manufacturing processes discovered by engineers, because these human technologies have more of the characteristics of life. Although Biomimetics offers enormous potential for novel designs, we must realize that nature is constrained by evolution, development, multi-functionality and sexual selection. Principles for legged motion systems that have emerged include self-stabilization, self-righting, self-cleaning fibrillar adhesives, self-reconfiguring antennae, robustness in leg design, terradynamic streamlining through multi-component 3D environments and the ability of soft bodies with legs to permit ingress into confined spaces.

9467-67, Session 13

Real-time atmospheric imaging and processing with advanced adaptive optics and algorithm acceleration systems *(Invited Paper)*

Jony J. Liu, Leonid A. Beresnev, John E. McElhenny, Gary W. Carhart, U.S. Army Research Lab. (United States); Fouad E. Kiamilev, Univ. of Delaware (United States)

For a tactical long-range imaging and reconnaissance system, atmospheric turbulence poses significant challenge for its performance in target identification and recognition. In our efforts to solve this problem, we developed an advanced adaptive optics (AO) system, which contains high-performance deformable mirrors (DMs) with the fast stochastic parallel gradient decent (SPGD) control mechanism. It allows the effective compensation of such turbulence-induced wavefront aberrations and results in significant improvement on the image quality. In addition, we applied a sophisticated digital synthetic imaging and processing technique, "lucky-region" fusion (LRF), to mitigate the image degradation over a large field-of-view (FOV) region. The LRF algorithm extracts sharp regions from each image obtained from a series of short exposure frames and fuses them into a final improved image. We further developed hardware electronics and implemented such algorithm into a field programmable gate array (FPGA) processor. The system achieved real-time image/video acquisition and processing. We will present these experimental results for combining both AO and hardware implemented LRF processing technique over a near-horizontal 2.3km atmospheric propagation path. Our approach can also generate a universal camera-independent real-time imaging and processing system.

9467-68, Session 13

Ultraspectral imaging and the snapshot advantage *(Invited Paper)*

Michael W. Kudenov, Subharup Gupta Roy, Bryan D. Maione, North Carolina State Univ. (United States)

Ultraspectral sensing has been investigated as a way to resolve terrestrial chemical fluorescence within solar Fraunhofer lines. Referred to as Fraunhofer Line Discriminators (FLDs), these sensors attempt to measure "band filling" of terrestrial fluorescence within these naturally dark regions of the spectrum. However, the method has challenging signal to noise ratio limitations due to the low fluorescence emission signal of the target, which is exacerbated by the high spectral resolution of the sensor (<0.1 nm). To now, many Fraunhofer line discriminators have been scanning sensors; either pushbroom or whiskbroom, which requires temporal and/or spatial scanning to acquire an image. In this paper, we attempt to quantify the snapshot throughput advantage in ultraspectral imaging for FLD. This is followed by preliminary results of our snapshot FLD sensor. The system has a spatial resolution of 280x280 pixels and a spectral resolving power of approximately 10,000 at a 658 nm operating wavelength.

9467-69, Session 13

Design and characterization of a tunable opto-mechatronic system to mimic the focusing and the regulation of illumination in the formation of images made by the human eye *(Invited Paper)*

Agustín Santiago-Alvarado, Angel S. Cruz-Félix, Arturo Hernández Méndez, Yara Pérez-Maldonado, Cristian Dominguez Osante, Univ. Tecnológica de la Mixteca (Mexico)

Nowadays, tunable lenses have attracted much attention due to their potential applications in such areas like machine vision, laser projection, ophthalmology, etc. In this work we present the design of a tunable opto-mechatronic system capable of focusing and to regulate the entrance illumination that mimics the performance made by the iris and the crystalline lens of the human eye. A solid elastic lens made of PDMS has been used in order to mimic the crystalline lens and an automatic diaphragm has been used to mimic the iris of the human eye. Also, a characterization of such system has been performed by means of interferometric techniques and standard values of luminosity for the human eye have been taken into account to calibrate and to validate the entrance illumination levels to the overall optical system.

9467-70, Session 13

Selective broadband jitter mitigation for non-common path errors *(Invited Paper)*

Edwin S. Ahn, Richard A. Carreras, Air Force Research Lab. (United States); Steve Gibson, Univ. of California, Los Angeles (United States)

Beam control systems that address optical jitter frequently experience non-common path errors where the sensor used for feedback detects additional measurements that are non-correlated to the disturbance of interest. Correcting for this additional disturbance can result in overcompensation, thus degrading overall error rejection performance. Previous methods that were used to curb this non-common-path error implemented notch or band-stop filters to suppress frequency content within the control signal that were correlated to the non-common path disturbance. Two new design methods are introduced here that provide autonomous-like behavior within the design process and results in improving the accurateness of rejection.

The first algorithm, which is the Clearbox algorithm, takes a system identification perspective where both disturbance and plant dynamics are incorporated within the model. Disturbance modes within the Clearbox model can be conveniently detected within the model itself and selectively removed from the model based on auxiliary sensor readings which then leaves it up to the controller to reject. Modes that are correlated to the non-common path disturbance may be left within the Clearbox model so that these disturbance components are not eliminated, hence providing capabilities for selective disturbance rejection. The Clearbox algorithm effectively treats the non-common path modes as part of the plant and bypasses potential rejection. Due to the algorithm's disturbance identifying capability the design process for selectively rejecting modes is autonomous to a certain degree and displays a major benefit over the baseline approach of applying a suppressing filter to the outputting control command signal when the common and non-common disturbances are temporally close together.

The second algorithm is more adaptive in nature, and uses an adaptive minimum variance lattice filter to selectively segregate the common-path signal from the combined common and non-common path disturbance signal. The approach effectively uses a real-time adaptive correlation algorithm between an auxiliary measurement of the non-common path and the mixed signal to identify the non-common-path portion of the combined disturbance signal. Once this has been determined, the signal is negated from the combined signal to extract a common-path reference sequence that is used for a receding horizon rejection controller. Provided that the auxiliary measurement reasonably represents the non-common path disturbance, the algorithm demonstrates adaptive behavior that can adjust to non-common path disturbances that have non-stationary statics which is a contrasting advantage over both the baseline and Clearbox algorithm approach.

Overall, the two algorithms display autonomous-like behavior that can increase the accurateness of the selective rejection process, which in result shows better performance over the baseline method for numerous disturbance frequency profiles.

9467-71, Session 13

Beam optimization for imaging lidar *(Invited Paper)*

Lyle Ruppert, Ball Aerospace & Technologies Corp. (United States)

Active remote sensing returns information of the highest value at the lowest cost when outgoing energy can be carefully shaped and directed to the task at hand. This paper presents results of lab and airborne testing of an Electronically Steerable Flash Lidar (ESFL) under continuing development by Ball Aerospace and Technologies Corp. The results highlight the adaptive nature of this and other active instruments having fine control of illumination, and show the benefits of combining lab simulation with flight testing in validation of algorithms and control design.

9467-72, Session 14

Photonic RF-IF wideband down conversion using optical injection locking *(Invited Paper)*

James R. Adleman, SPAWAR Systems Ctr. (United States); Chunyan Lin, Space and Naval Warfare Systems Command (United States); Shai Barak Jester, B. Melvin L. Pascoguin, Douglass Evans, SPAWAR Systems Ctr. (United States); Everett W. Jacobs, Space and Naval Warfare Systems Ctr. Pacific (United States)

We describe the implementation of a self-heterodyne down converting RF photonic link as a key component of a wideband microwave signal search and intercept system. The presented architecture uses photomixing of two distributed feedback lasers injection locked to a master external cavity laser. Coherent detection and digitization of the intermediate frequency allows unambiguous recovery of full time-domain information within a 1.7 GHz bandwidth. The injection locked laser design relaxes tuning range requirements of RF local oscillator, and provides high optical power for efficient RF-IF conversion without the use of an erbium doped fiber amplifier. The demonstrated link has better than 110 dB/Hz^2/3 spur free dynamic range and noise figure better than 36 dB from C to Ka band. Analysis of the phase noise performance of the injection locked lasers and their impact on system sensitivity is presented. Additionally, the practical implementation of a packaged prototype system will be discussed, with emphasis on the system stabilization strategy and performance requirements.

9467-73, Session 14

Wideband RF channelizer based on parametric combs *(Invited Paper)*

Sanja Zlatanovic, Space and Naval Warfare Systems Command (United States)

RF photonic channelizers can overcome limitations of conventional electronic methods for analysis of wideband RF spectral content. Here, we will present recent progress on the RF photonic channelizer systems that are based on optical parametric combs. These systems can analyze very wide RF bandwidths exceeding 100GHz, therefore providing essential capability for the applications demanding a wide-bandwidth spectral analysis. The RF channelizers being presented utilize parametric processes in the highly non-linear fiber mixers to generate a large number of RF signal copies in the optical domain. Two different implementations for generation of RF signal copies will be presented and compared: one using a parametric multicasting and another utilizing a direct comb modulation. Generation of optical combs spanning more than 10THz will be shown. We will also present two distinct system architectures for RF photonic channelizer system: one employing a periodic optical filter such as Fabry-Perot etalon to select channels from the signal comb, and another one utilizing a coherent detection between a frequency-locked signal comb and a parametrically generated local oscillator (LO) comb. The second scheme gives benefit of providing both in-phase and quadrature (I/Q) information on channelized intermediate frequency (IF) signals. We will present a system with 32 implemented channels using a filtered scheme and an 88-channel coherent system with a full-field detection implemented on one channel. Sensitivity and dynamic range as well as benefits of both system architectures will be discussed.

9467-74, Session 14

Optical channel characterization in maritime atmospheres *(Invited Paper)*

Stephen M. Hammel, Dimitri Tsintikidis, John S. deGrassie, Colin Reinhardt, Kevin M. McBryde, Eric Hallenborg, David T. Wayne, Kristofor Gibson, Galen Cauble, Ana Ascencio, Joshua J. Rudiger, Space and Naval Warfare Systems Command (United States)

The Navy is actively developing diverse optical application areas, including high-energy laser weapons and free-space optical communications, which depend on an accurate and timely knowledge of the state of the atmospheric channel. We have created a comprehensive program to coalesce and extend the current capability to characterize the maritime atmosphere for all optical and infrared wavelengths. The program goal is the development of a unified and validated analysis toolbox.

A salient feature of the maritime atmospheric propagation channel is its highly variable nature. This variability is also multi-factorial, depending upon geography, season, and engagement geometry. The conclusion that must be drawn is that a successful prediction and analysis capability will necessarily combine multiple approaches operating in 'parallel'. Furthermore, any such performance prediction for working optical system must evolve towards a near-real-time channel assessment. The foundational design for this program coordinates the development of sensors, measurement protocols, analytical models, and basic physics necessary to fulfill this goal. An overview of these core elements will be presented.

A second fundamental goal for this project is to extend the characterization of the maritime atmospheric propagation channel throughout optical electromagnetic spectrum from visible(VIS) wavelengths through short-wave-infrared (SWIR), mid-wave infrared (MWIR), and long-wave infrared (LWIR). More comprehensive understanding of propagation channel characteristics is a first-order requirement for the dominant Navy optical systems. Our knowledge of spectral details of optical propagation in maritime environments is incomplete, and this project will contribute to its completion. We will gain a clearer understanding of the relevant propagation physics by analysis of scattering and attenuation by the atmospheric aerosol/particulate distributions and turbulent scintillation phenomena that cause rapid fluctuations of the amplitude and phase of the received signal.

9467-75, Session 14

Wavelength optimization via retroreflection for underwater free-space optical communication *(Invited Paper)*

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The wireless, high-data-rate transmission of information is becoming increasingly important for undersea applications that include defense, environmental monitoring, and petroleum engineering. Free-space optical (FSO) communication addresses this need by providing an undersea high-data-rate link over moderate distances (up to 100s of meters). Light transmission through seawater is maximal in the blue-green part of the optical spectrum (475 nm-575 nm), but turbidity conditions, which are dynamic, strongly influence the observed maximum. We describe the development of a laser-wavelength auto-selection algorithm and system for optimized underwater FSO communications. The use of a passive corner-cube retroreflector allows all transmitter and receiver electronics to be collocated, which will be beneficial on any fielded system. First, we present results on creating various seawater types (from clear to turbid) in the laboratory using particle suspensions and dyes, which will enable wavelength-dependent transmission tests. Next, we describe the laser test bed and retroreflector system. We then show experimental results from water tube tests. Finally, we describe the development of the auto-selection algorithm. This wavelength auto-selection system has the potential to improve undersea optical link reliability for high-data-rate communications.

9467-76, Session 14

Preparation of novel HTS films and tunnel junctions for advanced C3I sensor applications *(Invited Paper)*

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Research is being carried out in the Cryogenic Exploitation of Radio Frequency (CERF) laboratory at Space and Naval Warfare Systems Center Pacific (SSC Pacific) into the development of advanced RF sensors known as Superconducting Quantum Interference Device (SQUID) arrays made from the high-temperature superconductor YBa2Cu3O7–.δ In support of this, a basic scientific research effort was begun wherein fundamental properties of the compound YBa2Cu3Ox ($6 \leq x \leq 7$) were investigated along with the exploration of new combinations of multilayer hetero-structures composed of YBa2Cu3Ox and multiferroic materials. A significant result from this project involved the invention of a novel method and subsequent development of an apparatus by which a single film could be grown with a monotonically varying oxygen content as a function of the physical distance along the sample, which we refer to as YBa2Cu3OΔx. The purpose of this approach is to enable an examination of the evolution of? the electronic tunneling properties as a function of oxygen content in a nearly continuous fashion, thereby providing an experimental resolution heretofore unobtainable. Josephson junctions can be fabricated via many known methods; however, a particularly useful method for our purposes involves the use of a directed ion beam to disorder or mill away a region of the film. Because the ion milling process is material dependent it becomes necessary to establish whether, and to what extent, the level of oxygen affects the resulting junction formation geometry. We find a positive correlation of local oxygen content and ordering on the depth and profile of micrometer scale ion milled trenches. It appears that the change in the ion milling profile can be used advantageously in the fabrication of Josephson junction on films of $YBa_2Cu_3O_{7-\delta}$, wherein the film is annealed such that the oxygen content of the sample is set to an ideal level for a controlled profile result, and then re-annealed for desired electronic properties.

9467-103, Session PThu

Lowering contact resistance of graphene FETs with capacitive extension of ohmic contacts for enhanced RF performance

Chowdhury G. Al-Amin, Mustafa Karabiyik, Raju Sinha, Nezih Pala, Florida International Univ. (United States)

We propose a novel Graphene Field Effect Transistor (GFET) with two Capacitively Coupled Contacts (C3) at the access regions that are shorted to the ohmic Source/Drain. The capacitive extension of ohmic contacts towards the Gate serves as a low impedance route for the high frequency RF signal, in parallel to the ohmic contact. The DC bias required for signal amplification is applied at the ohmic Source/Drain, whereas the amplified RF signal avails both the ohmic Drain and Drain-side C3, to be received as output. As the imaginary part of C3 impedance can be nullified by using a suitable matching network, the paralleling of Drain resistance and real part of C3 impedance results in an overall lower contact resistance. The current gain cut-off frequency, fT is inversely dependent of contact resistance for RF FETs and this paralleling eventually results in a higher fT of the proposed GFET. As the C3s, starting from Source/Drain, extend towards the Gate, it reduces the access region length and the reduction of access resistance contributes towards the increment of fT as well.

As a starting point of our analysis, we simulated a baseline GFET with ohmic Source/Drain contacts. It consists of Lg=3.0 ?m and Lgs/Lgd=1.5 ?m with SiO_2 as substrate and 24 nm thick dielectric on top of CVD Graphene. We simulated the DC and RF characteristics of the baseline GFET using physics based numerical device simulation tool along with analytical calculations. The simulated DC and RF characteristics were in good agreement with the reported characteristics.

To estimate the impedance of C3, we simulated a RF TLM structure on Graphene having two Capacitively Coupled Contacts with various in-between distances. Graphene carrier mobility, dielectric thickness, and material were considered the same as that in baseline GFET.

Finally, we simulated our proposed GFET. We started with a capacitive extension of 0.8 ?m. The AC simulation was performed for the DC biasing of Vds=5.0V. As the drain bias as well as the drain side C3 bias is positive, we considered the GFET electron regime operation so that the drain side C3 bias does not deplete, rather accumulate more major carriers. A gate bias of Vgs=2V was used to operate the GFET in electron regime. Later, the effect of increasing C3 length on cut-off frequency was examined and the length was extended up to a maximum of 1.4 ?m. The simulation results were verified through analytical calculations.

Expected similar improvement of fT for shorter channel high mobility GFET was also estimated from simulation and analytical calculations.

In conclusion, capacitive extension of ohmic Source/Drain lowers contact resistance and access resistance which eventually increases the current gain cut-off frequency. Our simulation results supported by analytical calculations show that, with a capacitive extension of 0.8 ?m, the increment was 9.0% and for a maximum extension of 1.4 ?m, it reached up to 18.9%. For shorter channel GFET, the improvement was even more prominent and reached up to 23.4%. The proposed Graphene FETs with improved characteristics can be used for high frequency applications.

9467-104, Session PThu

Development of small-sized accelerometer

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The possibility of manufacturing compact accelerometer based on prefabricated elements has been shown. Since most of the sensitive element designs at the lowest cost possible to produce at different ranges of sensitivity, so accelerometer design will be flexible in terms of wide range measuring of linear accelerations. Structurally, the accelerometer consists of a sensor (comb type), capacitance-to-voltage converter (CBC) with digital interface settings and microcontroller for storing CBC register values in nonvolatile memory. Measuring the change of sensitive element capacitance when exposed to acceleration is the main circuit operation principle. Structurally CBC glued to the microcontroller in the immediate vicinity of the sensitive element. Surface protected by the microcontroller mask, so the adhesive can be both conductive and non-conductive, with the tolerances set to 100 microns. The housing is sealed by suture-seam welding, and the accelerometer interior is filled with nitrogen. This operation is a standard operation for encapsulation majority of chips, which gives an advantage in the product processability. In this case, the bandwidth of the test specimen was about 320 Hz. Process of accelerometer setting up and testing is to install the housing in contact device, and firmware of the microcontroller software. This method allows you to configure the accelerometer “on the fly” directly on the centrifuge or on a vibrating table. Advantages of this product are the ability to change the sensitive element, experimenting with its design and manufacturing technology, manufacturability, work in a wide temperature range from minus 60°C to plus 85 °C.

9467-105, Session PThu

Comb structure analysis of the capacitive sensitive element in MEMS-accelerometer

Sergey P. Timoshenkov, Andrey Shalimov, National Research Univ. of Electronic Technology (Russian Federation); Natalia Korobova, National Research University (MIET) (Russian Federation); Mikhail Golovinskiy, National Research Univ. of Electronic Technology (Russian Federation); Alexey Timoshenkov, Egor Zuev, Svetlana Berezueva, Andrey Kosolapov, National Research University (MIET) (Russian Federation)

In this paper, an analysis of comb design for the sensing element MEMS accelerometer with longitudinal displacement of the inertial mass under the influence of acceleration to obtain the necessary parameters for the further construction of an electronic circuit for removal and signal processing has been done. Fixed on the stator the inertia mass has the ability to move under the influence of acceleration along the longitudinal structure. As a result the distance between the fixed and movable combs, and hence the capacitance in the capacitors have been changed. Measuring the difference of these capacitances you can estimate the value of the applied acceleration. Furthermore, managing combs that should apply an electrostatic force for artificial deviation of the inertial mass may be used for the initial sensitive elements culling. Also in this case there is a change of capacitances, which can be measured by the comb and make a decision about the spoilage presence or absence. The paper establishes the relationship between the geometrical dimensions of the comb and the functional parameters of the final product (accelerometer). Simulation results in the Ansys application have been presented.

9467-106, Session PThu

A bimorph electrothermal actuator for micromirror devices

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The paper presents a structure of micromechanical bimorph electrothermal actuator for use in optical systems for light beam control. The actuator is a thin structure which consists of layers of silicon dioxide and aluminum, with a polysilicon heater placed between them. The actuator is created on the surface of a standard silicon wafer using processes and technologies of microelectronics such as oxidation of the silicon wafer, the epitaxial growth of silicon dioxide, polysilicon deposition and deep anisotropic etching of silicon. Heating of electrothermal actuator structure leads to a different linear expansion of aluminum and silicon dioxide. That bends the actuator beam in the desired direction, thus creating a movement that could be used in device. A mathematical model of the electrothermal actuator and a method of calculating the movement of the beam end depending on its geometrical, technological and electrical parameters are proposed in the paper. Proposed method takes into account the temperature distribution along the entire length of the actuator beam and allows to get more accurate data on the radius of curvature of the actuator compared to models in which temperature is constant along the entire length of the beam. Paper also describes the design and manufacturing process of a several micromirror prototypes driven by the developed actuator. Micromirrors have dimensions of 50x50μm, 100x100μm and 200x200μm and a large deflection angle of about ~30°. A method for experimental testing of micromirror deflection angle is also proposed. It is established that experimental results are in good agreement with the mathematical model.

9467-108, Session PThu

A novel class of MEMS accelerometers for guidance and control of gun-fired munitions

Jahangir Rastegar, Dake Feng, Omnitek Partners, LLC (United States); Carlos M. Pereira, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

The state of the art in shock resistant MEMS accelerometer design is to reduce the size of the proof mass, thereby reducing the generated forces and moments due to shock loading. Physical stops are also provided to limit proof mass motion to prevent damage to its various moving components. The reduction of the proof mass size reduces the sensor sensitivity. In addition, to increase the sensor dynamic response, proof mass motion needs to be minimally damped, resulting in a significant sensor settling time after experiencing a high acceleration level such as those experienced by gun-fired munitions during firing. The settling time is particularly important for accelerometers that are used in gun-fired munitions and mortars for navigation and guidance.

This paper describes the development of a novel class of accelerometers that are provided with the means of locking the sensor proof mass in its “null” position when subjected to acceleration levels above those that are intended to sense during its normal operation, thereby protecting the moving parts of the accelerometer during very high shock loading events. In munitions applications, the proof mass is thereby locked in its null position during the firing and released during the flight to begin to measure flight acceleration with minimal settling time. The paper describes details of the design and operation of the developed sensors and results of their prototyping and testing. The application of the developed technology to other types of inertial sensors and devices is also discussed.

9467-109, Session PThu

Fiber-based split-ring-resonators: producing strong magnetic response in the IR through an electrospinning technique

Tao Gong, Jeremy N. Munday, Univ. of Maryland, College Park (United States)

We investigate the properties of a fiber-based split ring resonator (SRR) with a strong resonance in the near-IR wavelength range for application as a sensitive IR detector and as a critical component for a negative-index material (NIR). The fiber-based SRR allows for direct coupling of magnetic field into the LC resonance under normal incidence, contributing to a negative magnetic permeability, which is not possible for a planar SRR array. We systematically study the influence of resonator size, periodicity, and metal coating thickness on the resonance properties, in which a parameter-retrieval method is utilized to obtain the permittivity and permeability of the SRR. The diffraction, induced dipole-dipole coupling, and current distribution are studied and used to explain these unique properties. A simple experiment is also discussed, which employs an electrospinning technique to make the long fibers followed by metal deposition. This method could be used for large-scale, cost-effective SRR fabrication.

9467-110, Session PThu

Thermal conductivity characterization of in-situ fabricated polysilicon nanowires for uncooled thermoelectric infrared detectors

Mohammad J. Modarres-Zadeh, Univ. of Central Florida (United States); Nahida Akhter, Intel Corp. (United States); Ron Hellmer, Micheal Aragon, Amethyst Research Inc. (United States); Reza Abdolvand, Univ. of Central Florida (United States)

In this work, a microstructure along with its fabrication process has been developed for measuring the thermal conductivity (K) of nanowires and thin films. The nanoscale features are embedded in the device during the fabrication process using e-beam lithography. Using this microstructure, the K of polysilicon nanowires are measured for the first time and it is shown that for nanowires with a cross section of ~60nmx100nm, the K is ~3 W/m.K (a 10X reduction compared to the bulk value of ~30W/m.K [1]).

The K of a thermoelectric material is the most difficult material parameter to measure. The lower the K, the higher is the thermoelectric efficiency and hence a better infrared detector can be made. We have previously shown high responsivity uncooled thermoelectric IR detectors [2] that were utilizing polysilicon as the thermoelectric material. To further improve the performance of our devices, it is required to know how the dimensions of the wires and different deposition parameters affect the polysilicon K.

In this MEMS structure [3,4], nanowires are formed between two membranes that are suspended from the substrate by 450um long arms and a metallic coil is used as a heater/thermometer on each membrane. One of the membranes is heated by passing a DC current through its coil. The temperature of the second membrane rises due to the heat conducted through the nanowires. Knowing the generated heat in the structure and the temperatures of the membranes, the thermal conduction of the nanowires is calculated. The results obtained here will be used to fabricate more sensitive IR detectors.

9467-111, Session PThu

Two-photon absorption based optical logic

Xiang Zhang, Wenbo Li, Hongyu Hu, Niloy K. Dutta, Univ. of Connecticut (United States)

We have studied high speed optical logic utilizing ultrafast two-photon absorption (TPA) induced phase change in semiconductor optical amplifiers (SOA). The Boolean logic studied are XOR, AND and NAND. The input optical intensities to the SOA are high enough so that the fast two-photon absorption induced phase change is the dominant phase change. We also propose a scheme to realize high speed all-optical encryption using key-stream generators and an optical XOR gate. The key used for encryption is a high speed all-optical pseudorandom bit sequence (PRBS) which is generated by a linear feedback shift register (LFSR) together with optical XOR and AND gates. Several key stream generators have been studied. Results show that this scheme can realize all-optical logic and encryption at data speeds to 250 Gb/s.

9467-112, Session PThu

Mode-locked fiber ring laser using graphene as saturable absorber

Hongyu Hu, Xiang Zheng, Wenbo Li, Niloy K. Dutta, Univ. of Connecticut (United States)

A fiber ring laser which generates ~ 3 ps wide pulses at 10 and 20 GHz repetition rate has been demonstrated using graphene as a saturable absorber within the ring cavity. RF spectrums show that noise is low in the presence of the saturable absorber. The compression of these pulses to < 1ps pulse width using a photonic crystal fiber as a nonlinear optical loop mirror (NOLM) is described. Theoretical simulation of the NOLM transmission has been carried out using the split-step Fourier method.

9467-113, Session PThu

Characterization of planar 6x6 cm2 MCP-based picosecond photo-detectors

Jingbo Wang, Karen Byrum, Marcel Demarteau, Edward A. May Jr., Robert G. Wagner, Dean Walters, Lei Xia, Junqi Xie, Huyue Zhao, Argonne National Lab. (United States)

Microchannel plate (MCP)-based photo-detectors are capable of mm-level spatial imaging and picosecond-level timing performances, making them a promising candidate for the next generation photo-detectors. Their excellent performances allow for a replacement of the traditional photomultiplier tubes (PMT), which would open a lot of possibilities for a wide variety of applications in fields of imaging, high energy physics and astrophysics.

At Argonne National Laboratory (ANL), we are currently producing 6x6 cm2, cost-effective, thin planar, glass-body, MCP-based photo-detectors at a newly constructed production facility. We have successfully developed a technique to make an indium vacuum seal and produced a number of photo-detectors. The performances of these detectors have been characterized with a pulsed blue laser test facility. We have measured time-of-flight resolution up to 20 ps, differential time resolution of 8 ps, and spatial resolution better than 1 mm. Here we present the experimental setup, data acquisition, analysis tools, characterization of the photo-detectors, and typical results demonstrating the accuracy of the test facility. A new design of the photo-detector is also being considered for optimization.

9467-115, Session PThu

Sensors application using microcontroller

Huthaifa A. Al Issa, Univ. of Dayton (United States)

Sensors are used in everyday aspects such as touch-sensitive elevator buttons and lamps which dim or brighten by touching the base. There are also innumerable applications for sensors of which most people are never aware about. Applications include cars, machines, aerospace, medicine, manufacturing and robotics.

The conducted research studies sensors types and data that's comes out from sensors and how can be used with microcontroller to build devices that's solve problem related to the need monitoring some physical variation such as temperature, distance and lighting control.

Sensors types planning to be used in the algorithm include:

Ultrasonic sensor which is used for measuring the distance between the device and an object. Temperature sensor for monitoring temperature change. As well as light sensor which monitors different levels of light. In addition to the above the Light Depending Resistor (LDR) are used to detect light brightens in shaded areas.

Research aims to make smart device that can be used to solve some problem like temperature control or water range meter. Also, a blind stick can be informed bout distance of objective that's in front. Thus many applications can be enhanced based on this research.

9467-116, Session PThu

Super resolution infrared light field imaging using single carbon nanotube detector

Ning Xi, Michigan State Univ. (United States)

Computational photography which enhances or extends the capabilities of digital imaging is one of most rapidly developing research field in computer vision, image processing and applied optics. The output of these techniques can reconstruct information of scene which is not obtained by today's traditional camera. It also opens a new approach for light field sensing. In this work, by analyzing optics of single pixel imaging system, we present a novel design for single pixel light field camera, which allows for capturing high resolution light field by carbon nanotube based infrared photodetector. The spatial light modulator reflects objects and forms a virtual image behind the plane in which the mirror lies. It consists of millions micro scale 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 ultra high signal to noise ratio, and fast responsibility, will sum up all image information on it, without image shape effect. The proposed method will sample multiple angular images through different pin holes so that more information is captured. Then, a robust reconstruction algorithm is applied to recover high resolution image. The performance of high resolution single pixel light field camera can achieve million pixels image from angular images.

9467-122, Session PThu

Multiple-baseline detection of a geostationary satellite with the Navy precision optical interferometer (NPOI)

Henrique R. Schmitt, J. Tom Armstrong, Ellyn K. Baines, Sergio R. Restaino, James H. Clark, U.S. Naval Research Lab. (United States); James A. Benson, Donald J. Hutter, Bob T. Zavala, U.S. Naval Observatory (United States)

Using the Navy Precision Optical Interferometer (NPOI), we have made the first multiple-baseline interferometric detection of a satellite.

The observations, carried out during the March 2015 glint season, succeeded in detecting the DirecTV-7S satellite with interferometer baseline lengths of 8.8 m and 9.8 m and wavelengths from 850 nm to 550 nm, corresponding to a resolution of ~0.02 arcsec, or 4 m at geostationary altitude. This is the first multiple-baseline interferometric detection of a satellite.

9467-77, Session 15

High power lasers for infrared countermeasures, targeting and illumination, beacons and standoff detection of explosives and CWAs *(Invited Paper)*

C. Kumar N. Patel, Pranalytica, Inc. (United States)

In the era of asymmetric warfare and ever increasing dangers of urban terrorism, several critical needs have been identified:

1. The need for detection of potentially dangerous objects and environmental constituents from safe distances is becoming an urgent issue. The required "safe" distance depends on the mode of operation. For an individual on foot, standoff detection distance may be 25-50m, while for a vehicle traveling at 40 km/hr, the standoff detection requirement may be several hundred meters. In either of the situations, rapid and unequivocal identification of potential danger is necessary.

2. The need for safeguarding aircraft from MANPADS (infrared countemeasures).

3. Out-of-band targeting, illumination and beacons.

Of the technologies available for detection of explosives, CWAs and TICs, only optical technology satisfies the requirements of noncontact, nonlocal standoff detection. Standoff detection involves illuminating a potentially dangerous target (e.g., an IED) or a cloud of unknown gaseous composition with optical radiation that interacts with the dangerous substance, and analyzing the return signal from the target as a function of the optical wavelength. The return signal necessary for detection is determined by the available detectors and thus the standoff detection is governed by the optical power available for illuminating the remote object. Furthermore, for detection and identification of the danger, the optical radiation needs to tunable over the broad spectral region required to cover absorption spectra of the dangerous substance. To provide the necessary information on a timely basis, we also need to be able to rapidly tune the optical radiation over the broad spectral region. For many if not most applications of standoff detection SWaP issues are important. Finally the optical radiation must be eye safe.

For protection of aircraft from shoulder-fired missiles, the technological requirement is for broadband lasers that generate high powers in the 3.5 ?m to 5.0 ?m range. The required power levels are in few watts to tens of watts.

Out-of-band targeting. Illumination and beacon requirements arise because the currently used infrared systems use a spectral region where sensors and viewers are widely available, which robs the U.S. forces the advantage of surprise. Use of longer wavelength spectral regions, where IR viewers are not widely available, would restore the element of surprise. Here, in addition to the power required, SWaP issues are also very important.

The above requirements can only be met using lasers that operate in the mid wave infrared (MWIR) and long wave infrared (LWIR) regions. Quantum cascade lasers are the only primary lasers (directly converting electricity into optical power) that meet all the technical requirements. In this paper, I will describe our recent progress for increasing power output from MWIR and LWIR QCLs, and increasing tunability and speed of tuning of tunable MWIR and LWIR systems. In particular, we expect to obtain >10 W of MWIR power from a polarization combined QCL system. In the tunable area, we are targeting nearly one watt of tunable power in the LWIR region, with microsecond random access tunability.

9467-78, Session 16

Detector response to high repetition rate ultra-short laser pulses *(Invited Paper)*

Jason M. Auxier, Myron P. Pauli, U.S. Naval Research Lab. (United States); Michael K. Rafailov, DHPC Technologies (United States) and Univ. of Alberta (Canada); Michael K. Rafailov, DHPC Technologies, Inc (United States)

Optical nonlinearities in semiconductors and semiconductor detectors have been widely investigated and exploited for many scientific and industrial applications. The correlation of optical and electronic characteristics in these detector materials under exposure of ultra-short laser pulses at high pulse repetition rates is still not very well known. These effects may be quite beneficial for many applications ranging from chemical and biological sensing to light-induced superconductivity. In this paper, we discuss the effect of extended bleaching in order to demonstrate sensing applications of such phenomenon as an example. Pump-probe measurements in bulk semiconductors will be presented to quantify the transient absorption dynamics and relate this to the electronic response of the detector devices. This effect is not limited semiconductors and may affect other matter states and electronic structures, like dielectrics.

9467-79, Session 16

2-micron ultra-short pulse lasers *(Invited Paper)*

Shibin Jiang, AdValue Photonics, Inc. (United States)

Recently fiber lasers around 2 micron wavelength have attracted significant attention as thulium (Tm)-doped fibers exhibit excellent power scalability and high efficiency in a wide spectrum of laser gain between 1.8-2.1 micron. Laser sources around 2 micron are useful for a variety of applications including eye-safe LIDAR, medicine, spectroscopy, remote sensing and mid-infrared (IR) generation. The broad gain bandwidth makes Tm fiber an appropriate gain medium for ultrashort pulse generation.

In this presentation, high efficient and highly Tm-doped silicate fibers are first introduced. Then mode-locked Tm-doped and Tm-Ho-codoped silicate fiber lasers are presented. ~GHz high repetition rate mode-locked thulium fiber laser, stretched pulse mode-locking operation and normal dispersion dominated mode-locking operation are briefly discussed. Experiment results of all-fiber Tm-doped silicate fiber amplifiers for mode-locked pulses will be presented.

9467-80, Session 16

Ultrafast fiber lasers: practical applications *(Invited Paper)*

Igor Pastirk, TOPTICA Photonics Inc. (United States); Alexander Sell, Robert Herda, Andreas Brodschelm, Armin Zach, TOPTICA Photonics AG (Germany)

No Abstract Available

9467-81, Session 16

Plasmonic nanoantennas for enhanced midwave and longwave infrared imaging *(Invited Paper)*

David W. Peters, Thomas E. Beechem III, Stephen W. Howell, Jin K. Kim, Darin Leonhardt, Joel R. Wendt, John A. Montoya, Sandia National Labs. (United States)

Conversion of plane waves to surface waves prior to detection allows key advantages in changes to the architecture of the detector pixels in a focal plane array. We have integrated subwavelength patterned metal nanoantennas with various detector materials to incorporate these advantages: midwave infrared indium gallium arsenide antimonide detectors and longwave infrared graphene detectors.

Nanoantennas offer a means to make infrared detectors much thinner by converting incoming plane waves to more tightly bound and concentrated surface waves. Thinner architectures reduce both dark current and crosstalk for improved performance. For graphene detectors, which are only one or two atomic layers thick, such field concentration is a necessity for usable device performance, as single pass absorption is insufficient.

We will discuss Sandia's motivation for these devices. The simulation methodology and design rules will be discussed in detail. We will also offer an overview of the fabrication processes required to make these subwavelength structures on at times complex underlying devices based on III-V detector material or graphene. Finally, we will present our latest characterization results for both III-V and graphene structures.

9467-91, Session 16

Mid-infrared ultrafast fiber laser *(Invited Paper)*

Peng Wan, Lih-Mei Yang, Jian Liu, PolarOnyx, Inc. (United States)

Ultrafast laser at mid-IR wavelength is an important light source in many applications such as molecular identification, rapid detection of explosives, environmental monitoring, high-order harmonic generation and thermal imaging. High energy/high power mid-IR laser pulses have attracted extensive research interests recently and remarkable progress has been achieved. In this paper, the newest developments of ultrafast fiber lasers in mid-infrared regime at PolarOnyx Inc are presented. Several techniques are used to achieve mid-IR ultrafast pulses, including mode-locked Tm-doped fiber laser and Er:ZBLAN fiber laser, optical parametric oscillation (OPO), optical parametric amplification (OPA) and supercontinuum generation. These works lay out foundations for further extending the spectrum range as well as energy and power scaling of ultrafast fiber lasers.

9467-82, Session 17

Terahertz electronics for sensing and imaging applications *(Invited Paper)*

Michael Shur, Rensselaer Polytechnic Institute (United States)

Short channel field effect transistors implemented using different materials systems, such as silicon; III-V, III-N, graphene, and other 2D compounds can be used to detect sub terahertz and terahertz radiation terahertz radiation. Such detection was demonstrated in the frequency range from 0.1 to approximately 5 THz is enabled by the excitation of the waves of the electron density – plasma waves – that are rectified due to the device nonlinearities. The resulting response has the spatial resolution determined by the scale of the electric field distribution at the gate edges resulting in nanometer scale resolution. The temporal response is in the sub THz range. The operating temperatures range from cryogenic to elevated. The detectivity values in pW/Hz1/2 have been achieved and single subpicosecond pulses of THz radiation have been detected. The dynamic range is at least several orders of magnitude and is limited by the excitation of the shock waves in the device channels. This technology could enable a variety of sensing, imaging, and wireless communication applications, including detection of biological and chemical hazardous agents, cancer detection, short-range covert communications (in THz and sub-THz windows), and applications in radioastronomy and space research. Using silicon FINFETs and SOI transistors in plasmonic regimes is especially appealing because of compatibility with standard readout and image processing silicon VLSI components.

9467-83, Session 17

A compact THz imaging set-up at 750 microns *(Invited Paper)*

Linda E. Marchese, Marc Terroux, Alain Bergeron, INO (Canada)

Advances in infrared (IR) detector technologies over the last decade have led to compact low-cost thermal imaging systems that have become almost ubiquitous. They are now used in such market applications as automotive, security and construction. Terahertz (THz) imagers can take advantage of the state-of-the-art in the infrared domain to reduce their size and cost. Such an example is the IRXCAM-THz-384 Terahertz camera whose electronics core is based on the IRXCAM camera core and whose detector has been specifically designed for the THz. The 384 x 288 35-micron-sized pixel detectors of both cameras are uncooled microbolometers. A micro-electronics core is currently being developed for both platforms that will yield ultra-compact IR and THz cameras.

While IR systems are passive and thus do not require an illumination source, the THz system does. Thus, the THz source must be included when talking about overall imaging system size and cost. There are a wide variety of THz sources, from quantum cascade lasers on the optical side of the radiation spectrum to IMPATT diodes on the electrical side. When considering a source for a given application, the output wavelength, output power, size, weight and cost are primary factors that must be taken into account.

This paper presents a summary of results from a study of different THz sources, each emitting at a wavelength around 750 microns. NEP measurements were taken for each using the same IRXCAM-THz-384 camera. Discussion of the measurement set-ups and results is presented, as well as comparison of THz images.

9467-84, Session 17

Collection efficiency for millimeter and submillimeter-wave antenna-coupled detection *(Invited Paper)*

Brian A. Lail, Yuancheng Xu, Florida Institute of Technology (United States)

The goal in the design of an efficient and low-noise antenna coupled receiver is to achieve a maximal capture cross section for the incident electromagnetic radiation compared to the dimensions of the sub-wavelength sized sensor loading the antenna. Collection efficiency captures this concept of power output/input and is made up of several sub-efficiencies. In the ideal case all of the available, incident power is collected and transferred to the load. However, many of the fundamental limits of antennas are based on theory describing the transmitting mode, whereas certain questions remain open for receiving antennas. Textbook antenna theory predicts that only 50% of available incident power can be absorbed by an antenna, yet under specific conditions this limitation can be surpassed. Two considerations are presented; (1) fundamental limits on antenna absorption, and (2) practical participation of dissipative media in achieving impedance matching between antenna and load, and the associated performance compromise. Specifically we seek to determine whether antenna-coupled detectors can approach unity absorption efficiency under matched conditions. Further, we identify practical conditions that must be met in order to overcome fundamental limitations that inhibit total absorption. Then antenna loss is split into radiative and dissipative terms in order to identify trade-offs between impedance matching and radiation efficiency.

9467-85, Session 17

CMOS mm-wave system-on-chip for sensing and communication *(Invited Paper)*

Adrian J. Tang, Jet Propulsion Lab. (United States) and Univ. of California, Los Angeles (United States)

CMOS technology offers relatively low performance at mm-wave frequencies compared with other III-V technologies and the high levels of process variation further exacerbate design margins. This paper discusses several CMOS system-on-chip (SoCs) developed by JPL through collaboration with UCLA that use a self-healing approach to optimize mm-wave transceiver performance, as well as calibrate operation at runtime. Several applications will be discussed for mm-wave spectroscopy, radar, and communication systems, with SoCs demonstrated at V, W and D band.

9467-86, Session 17

Applications and challenges for MMW and THz sensors *(Invited Paper)*

John N. Sanders-Reed, The Boeing Co (United States)

MMW and THz sensors offer unique imaging capabilities and challenges. This presentation will provide a brief discussion of some of the application areas for these sensors, in particular imaging in Degraded Visual Environments (DVE). Comparisons with other sensing modalities will be provided discussing some of the relative strengths and weaknesses.

This presentation will provide a review of various DVE sensing technologies (active and passive MMW, THz, vis/IR, and obscurant penetrating lidar, along with a prior data such as synthetic vision. It will also discuss various applications ranging from rotorcraft landing, to nap of the earth flight and how the strengths and weaknesses of the different sensing modalities play into this.

9467-87, Session 17

Video rate imaging at 1.5 THz via frequency upconversion to the near-IR *(Invited Paper)*

Patrick F. Tekavec, Vladimir G. Kozlov, Ian McNee, Microtech Instruments, Inc. (United States); Yun-Shik Lee, Oregon State Univ. (United States); Konstantin L. Vodopyanov, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

We demonstrate video rate THz imaging by detecting a frequency upconverted signal with a CMOS camera. The source for the terahertz radiation is a double resonant optical parametric oscillator (OPO), synchronously pumped with pulses from a 1064 nm fiber laser. The OPO resonates signal and idler pulses that are spectrally separated by 1.5 THz. The high IR powers generated in the OPO cavity enable efficient difference frequency generation of THz pulses in a quasi-phasematched gallium arsenide (QPM-GaAs) crystal located inside the OPO cavity. The resulting THz radiation has an average power greateer than 1 mW, a linewidth of <100 GHz, and peak power of >2 W. The narrow bandwidth and high peak power enables nonlinear detection by upconversion to the mid-IR. By mixing the THz pulses with a portion of the fiber laser pump (1064 nm) in a second QPM-GaAs crystal, distinct sidebands are observed at 1058 nm and 1070 nm, corresponding to sum and difference frequency generation of the pump pule with the THz pulse. By using a combination of polarizer and spectral filter it is possible to isolate one of the sidebands from the strong pump light, resulting in a nearly background free signal. For imaging, the THz beam is collimated and is incident on a sample. The resulting diffracted light is collected by a lens placed one focal length away from the sample. The lens focuses the THz beam onto a quasi-phase matched GaAs sample placed one focal length form the lens. This Fourier geometry produces the spatial Fourier transform of the THz image at the nonlinear crystal. By using a large diameter pump beam at 1064 nm, the spatial components are upconverted to the near-IR, with the pump beam acting as a Gaussian filter for the spatial components. A second lens inverse transforms the upconverted spatial components, and the image is detected with a CMOS camera. We have obtained video rate images with spatial resolution of 1mm and field of view ca. 20 mm in diameter without any post processing of the data.

9467-102, Session 17

High power MWIR quantum cascade lasers and their use in intra-cavity THz room temperature generation *(Invited Paper)*

Mariano Troccoli, AdTech Optics, Inc. (United States)

We will present our results on high power mid-IR generation from single-emitter QCL devices. Besides their use as high power sources, the large nonlinearity associated with the inter-subband transitions of QC devices and the multi-stage engineering of the band structure makes QCLs a perfect tool for building multi-functional devices. The high power of the mid-IR generation, associated with the resonances built-in by design into the active material, allow for room temperature generation of multiple wavelengths, including frequency doubling to the lambda<3um range and difference frequency generation into the THz region of the spectrum.

In this talk we will review our most important high power mid-IR results across the mid and long-wave infrared (MWIR and LWIR) regions and show how they can be applied to the room temperature generation of light at frequencies otherwise unattainable by a standard direct-generation QCL design.

9467-88, Session 18

Solution-processed chalcogenide glass: a pathway toward novel materials and architectures for mid-IR photonics *(Invited Paper)*

Craig B. Arnold, TAG Optics, Inc. (United States)

Chalcogenide glass materials exhibit a variety of optical properties that make them desirable for near- and mid-infrared communications and sensing applications. However, the processing of these photorefractive materials for thin film applications or for the direct integration with sources or detectors is challenging. In this presentation, we discuss solution based processing (SP) techniques for chalcogenide glass materials that provide for a low cost, safe, and flexible method to create novel structures with optimized properties. We will review the general process and discuss the structural and chemical implications of producing films in this manner with particular emphasis on the photoresponsive behavior and creation of heterogeneous materials. Given a reliable solution based process, we discuss the use of traditional printing and soft-lithographic methods to produce integrated optical elements such as lenses and waveguides. A few examples will be introduced including multimode As_2S_3 waveguides directly coupled with quantum cascade lasers and single mode As_2S_3 waveguides and splitters produced on flexible and non-planar substrates. These solution-based methods enable a suite of processes that can be applied to chalcogenide solutions to create a diverse array of mid-IR optical and photonic structures ranging from <5 to 10's of μm in dimension.

9467-89, Session 18

Approaches to generation of tunable mid-IR ultrafast pulses with fiber sources *(Invited Paper)*

Alexander Sell, TOPTICA Photonics AG (Germany); Igor Pastirk, TOPTICA Photonics Inc. (United States); Andreas Brodschelm, Robert Herda, TOPTICA Photonics AG (Germany); Thomas Puppe, TOPTICA Photonics Inc. (Germany); Armin Zach, 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. DFG approach opens a practical way for frequency comb applications and tunable absolute optical frequency sources.

The power scalability of lasers with doped Thulium or Holmium fiber amplifiers in combination with Chalcogenide or ZBLAN fibers made it possible to generate supercontinua in the MID-IR. Generation of spectral ranges in MID-IR along with the availability of high power components, double clad doped gain fibers and LMA fibers for the 2?m and 1?m region enables "all fiber" compact and robust sources that can be man-portable.

9467-90, Session 18

Long wavelength mid-infrared from mixing two colors from a fiber amplifier *(Invited Paper)*

Siyuan Bian, Univ. of Waterloo (Canada); Sébastien Loranger, Raman Kashyap, École Polytechnique de Montréal (Canada); Donna Strickland, Univ. of Waterloo (Canada)

At Waterloo, we are developing a high power, short pulse, two-color, Yb:fiber amplifier system to generate the long wavelength (>15μm) side of the molecular fingerprint spectral region, by difference frequency mixing the two colors. This spectral region is important for trace gas detection of explosives. As an example, it has been shown that the strong spectroscopic signatures of a peroxide-based explosive triacetone triperoxide (TATP) occur between 15 and 20 μm. To date we have achieved a tuning range from 16 to 20 μm with a maximum average power of 1.7 mW. On the short wavelength side, the two colors would need to be pulled further apart, which requires a higher power seed to beat the amplified spontaneous emission that appears at the gain peak of the amplifiers between the two seed colors. On the long wavelength side, we are limited to 20 μm by the transparency region of the nonlinear crystals. We would like to find new nonlinear materials that have transparency from 1 to 30μm. If we could generate wavelengths from 15 to 30 μm with sufficient power, we could extend the spectral region to also cover 8 to 15μm by frequency doubling the longer wavelengths. We are currently working on replacing bulk optics in the system with fiber based optical elements to select the wavelengths as well as stretch and recompress the pulses in order to make the system compact and stable.

9467-92, Session 18

Mid-IR lasers based on transition metal and rare-earth ion doped crystals *(Invited Paper)*

Sergey B. Mirov, The Univ. of Alabama at Birmingham (United States) and IPG Photonics - Mid-Infrared Lasers (United States); Vladimir V. Fedorov, Dmitry V. Martyshkin, The Univ. of Alabama at Birmingham (United States); Igor S. Moskalev, Mike B. Mirov, Sergey Vasilyev, IPG Photonics - Mid-Infrared Lasers (United States)

Recent results on the development of Cr and Fe doped ZnSe and ZnS polycrystals and mid-IR lasers on their basis are presented.

Cr:ZnSe/S CW lasers power scaling was realized with the use of AR coated crystals in linear resonator configurations. We reached 30 W output power level using multi-element MOPA. Dispersive cavity enables 1900-3000 nm tuning range with typical linewidth of 0.1 nm, efficiency 40%, output power of 6W at central wavelength 2300-2400 nm and TEMoo mode of operation. We significantly improved output characteristics of polycrystalline Cr:ZnS/Se lasers in Kerr-Lens-Mode-Locked regime: 1.7 W average power at 55 fs pulse duration, 22 nJ pulse energy and 340 kW peak power with efficiency of 17% with regards to 1567 nm pump power from linearly polarized Er-fiber laser.

Recent progress in high power CW Cr:ZnSe lasers enabled their utilization as effective pump sources for Fe:ZnSe lasers. In non-selective Fe:ZnSe cavity (at 85K) 1.6 W output power at 4100 nm was obtained at 35 % 2800 nm pump efficiency. In dispersive cavity 3700-5000 nm tunability was achieved at 140 K with output power of 0.5 W at 4100 nm. In gain-switched regime both Fe:ZnSe and Fe:ZnS lasers operate at 300K and in nonselective cavity when pumped by gain-switched Cr:ZnSe laser radiation they feature output energies around 1 mJ at 1 kHz repetition rate, ~ 5-10 ns pulse duration, and ~ 30 % pump efficiency at 3950 and 4350nm, respectively. We also report a high energy free-running Fe:ZnSe laser pumped by a flashlamp pumped Er:YAG laser. Fe:ZnSe output energy up to 0.5 J has been demonstrated with a real optical efficiency of 32% with respect to pump energy.

9467-100, Session 18

Recent progress in quantum cascade external cavity laser systems optimized for mid-IR sensing applications *(Invited Paper)*

David B. Arnone, Leigh J. Bromley, David B. Caffey, William B. Chapman, Timothy Day, Allen Priest, Daylight Solutions Inc. (United States); Charles C. Harb, The Univ. of New South Wales (Australia)

The ability to detect, image and identify molecular species using mid-IR quantum cascade lasers is driving a host of sensing applications for them. As the landscape of established and emerging applications continues to expand, so do performance requirements for laser systems addressing these applications. Laser application requirements include: high brightness and low noise for high SNR; narrow linewidth for high spectral resolution for chemical specificity; fast tuning for high data acquisition rates; wide tuning to enable multiple species to be detected with one instrument; and high power for practical standoff distance. The high-brightness, CW or pulsed output, broad-tuning, narrow-linewidth, and low-noise capabilities External Cavity quantum cascade lasers (ECqcLs™)—and their compact, rugged nature—make them ideally suited to meeting these varied requirements. In this paper, we report on recent advances in commercial ECqcL systems optimized for sensing applications including: wider tuning ranges, lower Relative Intensity Noise (RIN) profiles, and fast scanning. We then discuss how these new performance capabilities stand to benefit different applications.

9467-93, Session 19

Quantum cascade laser frequency combs for spectroscopy *(Invited Paper)*

Jérôme Faist, ETH Zürich (Switzerland)

The quantum cascade laser has demonstrated the ability to provide gain over a very broad wavelength range. Recently, we have shown that such broadband devices, when operated in continuous wave, emit as a coherent optical comb1 in which the phase relation between the comb modes corresponds approximately to a FM modulated laser. By combining a Maxwell-Bloch equations and a modal decomposition, the nature of this mode-locking has been elucidated2 . We have also recently shown that these comb can also be produced in the THz region of the spectrum, and even covering a full octave in bandwidth. These new comb lasers enables the fabrication of a dual comb spectrometer based on a quantum cascade laser that offers a broadband, all solid-state spectrometer with no moving

parts and a ultrafast acquisition time. We demonstrate a spectrometer and its first proof-of-principle applications.

9467-94, Session 20

Broadband mid-IR frequency comb source for standoff chemical detection *(Invited Paper)*

Konstantin L. Vodopyanov, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Frequency-comb-based absorption spectroscopy in the molecular fingerprint part of the spectrum (2-12 ?m) has great potential for standoff chemical sensing because of massive parallelism of data acquisition. Especially attractive is dual-comb Fourier transform spectroscopy, where full advantage is taken of temporal and spatial coherence of frequency combs as well as of their broadband nature. The promise is high speed (1M spectral points in less than a second), broad spectral coverage (> one octave), superior sensitivity (< 1 part per billion in gas phase), high spectral resolution (100 MHz), and the possibility of absolute frequency calibration of molecular resonances. Here we report a dual-comb system based on a pair of near-degenerate optical parametric oscillators (OPOs) based on orientation-patterned GaAs (OP-GaAs) pumped by two mutually phase-locked femtosecond Tm-fiber lasers at 2-micron wavelength. High coherence and broad instantaneous spectral coverage (2.5 - 7 microns) make this system promising for chemical detection and trace molecular sensing.

9467-95, Session 20

Standoff trace detection of explosives with Infrared hyperspectral imagery *(Invited Paper)*

Frank Fuchs, Stefan Hugger, Jan-Philip Jarvis, Quankui K. Yang, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany); Fabian Zaum, Fraunhofer-IAF (Germany); Ralf Ostendorf, Christian Schilling, Wolfgang Bronner, Raschid Driad, Rolf Aidam, Joachim Wagner, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany)

Broadband tunable external cavity quantum cascade lasers (EC-QCL) have emerged as attractive light sources for mid-infrared (MIR) "finger print" molecular spectroscopy for e.g. detection and identification of hazardous chemical compounds. Compared to Fourier Transform Infrared (FTIR) spectrometers EC-QCL offer the advantage of a much higher spectral brightness, i.e. high output power within a narrow wavelength interval, as well as a collimated low-divergence output beam, enabling e.g. stand-off detection schemes. Here we report on the use of EC-QCL for the stand-off detection of explosives as a prototypical case study.

Reliable stand-off detection of residues of explosives is still a challenging task. Imaging MIR backscattering spectroscopy has been shown to be a promising technique for non-contact detection of traces of explosives on various surfaces. This technique relies on active imaging with MIR laser illumination at various wavelengths. Recording the backscattered light with a MIR camera at each illumination wavelength, the MIR backscattering spectrum can be extracted from the three-dimensional data set recorded for each point within the laser illuminated area. Applying appropriate image analysis algorithms to this hyper-spectral data set, chemically sensitive and selective images of the surface of almost any object can be generated. This way, residues of explosives can be clearly identified on the basis of characteristic finger print backscattering spectra and separated from the corresponding spectra of the underlying material. To achieve a high selectivity, a large spectral coverage is a key requirement. Using a MIR EC-QCL with a tuning range from 7.5 μm to 9.5 μm, different explosives such as TNT, PETN and RDX residing on different background materials, such as painted metal sheets, cloth and polyamide, could be clearly detected and identified. For short stand-off detection distances (<3 m), residues of explosives at an amount of just a few 10 μg, i.e. traces corresponding to a single fingerprint, could be detected. For larger concentration of explosives, stand-off detection over distances of up to 20 m has already been demonstrated.

These results clearly demonstrate the potential of QCL-based imaging backscattering spectroscopy for the detection of trace amounts of hazardous substances in relevant environments. There is further potential for increasing the detection range and/or field of view via up-scaling of the total power emitted by the illuminating laser system.

9467-96, Session 20

Ozone alteration for background references using QCL based mid infrared standoff spectroscopy *(Invited Paper)*

Inseok Chae, Univ of Alberta (Canada); Charles W. Van Neste, Thomas G. Thundat, Univ. of Alberta (Canada)

Mid infrared standoff spectroscopy using Quantum Cascade Lasers has been a focus of on-going research for many years. When attempting to detect trace analyte residues, the greatest challenge facing this technology is not in the lasers, but the difficulty in creating a spectroscopic background reference for an unknown surface. Such techniques as Differential Location Measurements fail when analyte concentrations are below 1 ?m/cm2. To overcome this challenge of unknown surface backgrounds, we propose a technique to briefly shift the IR absorption peaks of a target analyte by exposing the surface to a high intensity, alternating electric field in a standoff fashion. A spectrum of the surface with and then without the intense electric field is taken. The field-shifted spectrum acts as the reference background and is compared against the un-shifted spectrum, generating a differential signal used to identify the target analyte.

9467-97, Session 20

Toward the realization of a compact chemical sensor platform using quantum cascade lasers *(Invited Paper)*

Ellen L. Holthoff, Paul M. Pellegrino, Logan S. Marcus, U.S. Army Research Lab. (United States)

The Army is investigating several spectroscopic techniques (e.g., infrared spectroscopy) that could allow for an adaptable sensor platform. Traditionally, chemical sensing platforms have been hampered by the opposing concerns of increasing sensor capability while maintaining a minimal package size. Current sensors, although reasonably sized, are geared to more classical chemical threats, and the ability to expand their capabilities to a broader range of emerging threats is uncertain. Recently, photoacoustic spectroscopy, employed in a sensor format, has shown enormous potential to address these ever-changing threats, while maintaining a compact sensor design.

In order to realize the advantage of photoacoustic sensor miniaturization, light sources of comparable size are required. Recent research has employed quantum cascade lasers (QCLs) in combination with MEMS-scale photoacoustic cell designs. The continuous tuning capability of QCLs over a broad wavelength range in the mid-infrared spectral region greatly expands the number of compounds that can be identified. Results have demonstrated that utilizing a tunable QCL with a MEMS-scale photoacoustic cell produces favorable detection limits (ppb levels) for chemical targets (e.g., dimethyl methyl phosphonate (DMMP), vinyl acetate, 1,4-dioxane). Although our chemical sensing research has benefitted from the broad tuning capabilities of QCLs, the limitations of these sources must be considered. Current commercially available tunable systems are still expensive and obviously geared more toward laboratory operation, not fielding. Although the laser element itself is quite small, the packaging, power supply, and controller remain logistical burdens. Additionally, operational features such as continuous wave (CW) modulation and laser output powers while maintaining wide tunability are not yet ideal for a variety of sensing applications. In this presentation, we will discuss our continuing evaluation of QCL technology as it matures in relation to our ultimate goal of a universal compact chemical sensor platform.

9467-98, Session 20

Detection of trace explosives on relevant substrates using a mobile platform for photothermal infrared imaging spectroscopy (PT-IRIS) *(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 discuss the results of recent tests regarding standoff detection of trace explosives on relevant substrates using a mobile platform. We are developing a technology for detection based on 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 previously 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. Analytes tested include RDX, TNT, ammonium nitrate and perchlorates. Relevant substrates include metal, plastics, 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).

9467-99, Session 20

Standoff detection of chemical and biological threats using miniature widely tunable QCLs *(Invited Paper)*

Petros Kotidis, Erik R. Deutsch, Anish K. Goyal, Block Engineering, LLC (United States)

Block Engineering has developed products that utilize Quantum Cascade Lasers (QCLs) and infrared spectroscopy for chemical and biological detection. Chemical detection has been demonstrated for: (a) Chemical security of large scale critical facilities, using the LaserWarn™ System, (b) Detection of surface threats, using the LaserScan™ Analyzer, and, (c) Detection of disturbed earth for buried IEDs, using the LaserScan™-DE Analyzer. These applications were enabled by several key technical accomplishments. First, the QCLs in Block's products tune across a spectral range of more than 1000 cm-1 in a single unit, anywhere within the features-rich spectral range of 5.4-13 microns. Second, the QCLs tune across that range in a world-record speed of 40 msec, enabling real-time detection and handheld operation. Third, the QCLs are packaged in sealed, extremely compact modules, which dramatically reduce the overall size, weight and power consumption of the complete systems. It is also important to emphasize that all Block systems utilize eye-safe lasers. Furthermore, the LaserScan Analyzer has also been used to detect biological threats and, more specifically, it was used to identify bacteria on a variety of background surfaces.

9467-101, Session 21

Recent results on performance optimization of QCLs for consumption, spectral coverage and power *(Invited Paper)*

Antoine Müller, Richard Maulini, Stéphane Blaser, Alfredo Bismuto, Tobias Gresch, Romain Terazzi, Alpes Lasers SA (Switzerland)

In this presentation the results of the optimization effort performed at Alpes Lasers SA will be presented. For applications such as hand held batery powered apparatus, devices with total dissipation lower than one Watt are presented. Focus will also be put on applications related to broad spectral paterns, where devices with gain spanning over more than 250 cm-1 is useful. Finally watt level emission power will be presented in the 4 to 5 and 8 to 12 microns region.

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9468-1, Session 1

Multi-modal interaction for UAS control

Glenn Taylor, Ben Purman, Paul Schermerhorn, Guillermo Garcia-Sampedro, Robert Hubal, Soar Technology, Inc. (United States); Kathleen Crabtree, Booz Allen Hamilton Inc. (United States); Guillermo Garcia-Sampedro, Robert Hubal, Soar Technology, Inc. (United States); Kathleen Crabtree, Booz Allen Hamilton Inc. (United States); Allen Rowe, Sarah Spriggs, Air Force Research Lab. (United States)

Unmanned aircraft systems (UASs) have seen a dramatic increase in military operations over the last two decades. The increased demand for their capabilities on the battlefield has resulted in quick fielding with user interfaces that are designed more for engineers in mind than for UAS operators. UAS interfaces tend to support tele-operation with a joystick or complex, menu-driven interfaces that have a steep learning curve. These approaches to control require constant attention to manage a single UAS and require increased heads-down time in an interface to search for and click on the right menus to invoke commands. The time and attention required by these interfaces makes it difficult to increase a single operator's span of control to encompass multiple UAS or the control of sensor systems. In this paper, we explore an alternative interface to the standard menu-based control interfaces. Our approach in this work was to first study how operators might want to task a UAS if they were not constrained by a typical menu interface. Based on this study, we developed a prototype multi-modal dialogue interface for more intuitive control of multiple unmanned aircraft and their sensor systems using speech and map-based gesture/sketch. The system we developed is a two-way interface that allows a user to draw on a map while speaking commands to the system, and which provides feedback to the user to ensure the user knows what the system is doing. When the system does not understand the user for some reason – for example, because speech recognition failed or because the user did not provide enough information – the system engages with the user in a dialogue to gather the information needed to perform the command. With the help of UAS operators, we conducted a user study to compare the performance of our prototype system against a representative menu-based control interface in terms of usability, time on task, and mission effectiveness. This paper describes a study to gather data about how people might use a natural interface, the system itself, and the results of the user study.

9468-2, Session 1

A novel method for full position and angular orientation measurement of moving objects

Harbans S. Dhadwal, Jahangir Rastegar, Dake Feng, Philip Kwok, Omnitek Partners, LLC (United States); Carlos M. Pereira, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

Angular orientation of an object such as a projectile, relative to the earth or another object such as a mobile platform continues to be an ongoing topic of interest for guidance and/or steering. Currently available sensors, which include inertia devices such as accelerometers and gyros; magnetometers; surface mounted antennas; radars; GPS; and optical line of sight devices, do not provide an acceptable on-board solution for many applications, particularly for gun-fired munitions. We present a viable solution, which combines open-aperture sensors with custom designed radiation patterns and one or more amplitude modulated polarization scanning reference sources. Subsequently, the sensor system presents a new approach to angle measurements, with several key advantages over traditional cross-polarization based rotation sensors. Primarily, angular information is coded into a complex spatiotemporal pattern, which is insensitive to power fluctuations arising from environmental factors while making the angle measurement independent of distance from the referencing sources. Triangulation, using multiple sources, may be also used for onboard position measurement. Both measurements are independent of GPS localization; are direct and relative to the established local referencing system; and not subject to drift and/or error accumulation.

In this paper, we present the theoretical basis and the operation of the developed full position and angular orientation sensory system. Results of laboratory tests as well as range tests are also presented.

9468-3, Session 1

Towards contextual awareness in robot mapping: extracting semantic hierarchy from point cloud data

Carlos P. Nieto-Granda, Siddharth Choudhary, Georgia Institute of Technology (United States); John G. Rogers III, Jeffrey N. Twigg, U.S. Army Research Lab. (United States); Varun Murali, Henrik I. Christensen, Georgia Institute of Technology (United States)

Contextual awareness is a prerequisite for a better understanding of the environment. It can be a useful tool in decision making for tasks like deploying robots, planning and navigation. In this paper, we present a system which provides contextual awareness through layered access to different levels of semantic hierarchy.

Hierarchical semantic map is generated by recursively merging perceptually similar neighboring regions at each level. Lowest level in the hierarchy is represented using the discovered objects and planes. Labelled objects and planes at the lowest level provides the bottom-up information required to label the corresponding segments at other levels. Probabilistic reasoning is used to infer the labels.

Object representation helps in identifying loop closure when the robot sees the same object and for producing better object models when an object part undersegmented in a few frames matches to the full object model. Object recognition is done by finding the object representation with the maximum number of inlier correspondences with the current

object. If an object does not find the minimum number of inlier correspondences with any of the saved representations, it saves the representation of the current object. This follows an online learning framework, where the robot identifies potential objects and matches to other objects in the map, if none of them matches it hypothesizes that the potential object is a new object and therefore saves the representation.

We performed a series of experiments in simulation and real environments (MOUTs and university facilites). Our system was implemented on board two different mobile robots and we provided a user interface which the human can monitor and interact with the robot in real time. The visualization allows the user to get dynamic maps with specific information acquired from the hierarchical semantic map.

9468-4, Session 1

Natural interaction for unmanned systems

Glenn Taylor, Ben Purman, Paul Schermerhorn, Guillermo Garcia-Sampedro, Matt Lanting, Michael Quist, Chris

Kawatsu, Soar Technology, Inc. (United States)

Military unmanned systems today are typically controlled by two methods: tele-operation or menu-based, search-and-click interfaces. Both approaches require the operator's constant vigilance: tele-operation requires constant input to drive the vehicle inch by inch; a menu-based interface requires eyes on the screen in order to search through alternatives and select the right menu item. In both cases, operators spend most of their time and attention driving and minding the unmanned systems rather than on being a warfighter. With these approaches, the platform and interface become more of a burden than a benefit. The availability of inexpensive sensor systems in products such as Microsoft Kinect™ or Nintendo Wii™ has resulted in new ways of interacting with computing systems, but new sensors alone are not enough. Developing useful and usable human-system interfaces requires understanding users and interaction in context: not just what new sensors afford in terms of interaction, but how users want to interact with these systems, for what purpose, and how sensors might enable those interactions. Additionally, the system needs to reliably make sense of the user's inputs in context, translate that interpretation into commands for the unmanned system, and give feedback to the user. In this paper, we describe an example natural interface for unmanned systems, called the Smart Interaction Device (SID), which enables natural two-way interaction with unmanned systems including the use of speech, sketch, and gestures. We present a few example applications SID to different types of unmanned systems and different kinds of interactions.

9468-5, Session 1

Fusion of lidar and radar for detection of partially obscured objects

Jim Hollinger, Brett Kutscher, LSA Autonomy LLC (United States); Ryan R. Close, U.S. Army RDECOM CERDEC NVESD (United States)

The capability to detect partially obscured objects is of interest to many communities, including ground vehicle robotics. The ability to find partially obscured objects can aid in automated navigation and planning algorithms used by robots. Two sensors often used for this task are Lidar and Radar. Lidar and Radar systems provide complementary data about the environment. Both are active sensing modalities and provide direct range measurements. However, they operate in vary different portions of the radio frequency spectrum. By exploiting properties associated with the different frequency spectra, the sensors are able to compensate for each other's shortcomings. This makes them excellent candidates for sensor processing and data fusion systems. The benefits associated with Lidar and Radar sensor fusion for a ground vehicle application, using economical variants of these sensors, is presented. Special consideration is given to detecting objects partially obscured by light to medium vegetation.

9468-6, Session 1

3D environment modeling on uneven-terrain using 3D LIDAR and IMU for unmanned ground system

Kuk Cho, Korea Institute of Industrial Technology (Korea, Republic of); Muhammad Ilyas, Univ. of Science and Technology (Korea, Republic of); SeungHo Baeg, Sangdeok Park, Korea Institute of Industrial Technology (Korea, Republic of)

This paper describes a method about 3D environment modeling on uneven terrain using 3D LIDAR and IMU for unmanned ground systems. Currently, 3D environment modeling on highly uneven terrain is difficult problem in research community due to uncertainty of height estimation. To compute 3D modeling using a fusion method, all of sensors should be synchronized and properly compensated. In this work, we suggest a Kalman filter model with predict and update mechanism to enhance height estimation to build a 3D environment model. The height estimation for 3D terrain model is predicted using IMU based pose estimation while LIDAR measurements update the position of the vehicle. We experiment on real uneven-terrain to make 3D environment model with 3D pose estimation of the vehicle.

9468-7, Session 2

Motion compensation for structured light sensors

Debjani Biswas, Christoph Mertz, Carnegie Mellon Univ. (United States)

Structured light sensing is a common method for short range 3D measurements. It is employed in many industrial and consumer applications (e.g. Kinect). One limitation when these sensors are used around people is that the amount of light they can project is limited by eye-safety concerns. This is particularly relevant in outdoor environments where the ambient sunlight can be overwhelming. We have shown in the past that this ambient light can be suppressed by using a combination of three methods: Laser as illuminator with a bandpass filter, laser pulsing and synchronizing it with a fast shutter of the camera, and background subtraction. A drawback of the last method is that the sensor has to be stationary in order to take an image with and without the illuminator on. This necessitates the sensor system to be stationary during data taking. The contribution of this paper is a method to compensate for the motion if the system is moving. The key idea is to use video stabilization techniques that work even if the illuminator is switched on and off from one frame to another. We used OpenCV functions and modules to implement a robust and efficient method. We evaluated it under various conditions and tested it on a moving robot outdoors. We will demonstrate that one can not only do 3D reconstruction under strong ambient light, but that it is also possible to observe optical properties of the objects in the environment.

9468-8, Session 2

Active dictionary learning for image representation

Tong Wu, Anand Sarwate, Waheed U. Bajwa, Rutgers, The State Univ. of New Jersey (United States)

The study of sparse image representation with redundant dictionaries has been a growing interest within image processing. Recent works have demonstrated improvements in image representation by learning a dictionary from the training data instead of using a predefined one. Using a large training set to infer the dictionary may become computationally expensive. We propose a new approach, which we call pool-based active dictionary learning, in which the algorithm selects a subset of training samples for learning a dictionary. Our method sequentially selects samples to add to the dictionary inference in order to improve its representation performance. We evaluate our approach through numerical experiments involving real-world image data; the results of these experiments demonstrate the effectiveness of the proposed method.

9468-9, Session 2

RCTA capstone assessment

Craig Lennon, Barry Bodt, Marshal Childers, U.S. Army Research Lab. (United States); Robert M Dean, General Dynamics Land Systems (United States); Jean Oh, National Robotics Engineering Ctr. (United States); Charles A. DiBerardino, Terence Keegan, General Dynamics Land Systems (United States)

The Army Research Laboratory's Robotics Collaborative Technology Alliance (RCTA) is a program intended to change robots from tools that soldiers use into teammates with which soldiers can work. This requires the integration of fundamental and applied research in perception, artificial intelligence, and human-robot interaction. In October of 2014, the RCTA assessed progress towards integrating this research. This assessment was designed to evaluate the robot's performance when it used new capabilities to perform selected aspects of a mission.

The assessed capabilities included the ability of the robot to: navigate semantically outdoors with respect to structures and landmarks, identify doors in the facades of buildings, and identify and track persons emerging from those doors. We present details of the mission-based vignettes that constituted the assessment, and evaluations of the robots performance in these vignettes.

9468-10, Session 2

Semi-autonomous exploration of multi-floor buildings with a legged robot

Garrett J. Wenger, Aaron M. Johnson, Camillo J. Taylor, Daniel E. Koditschek, Univ. of Pennsylvania (United States)

We present preliminary results of a semi-autonomous building exploration behavior using the hexapedal robot XRHex. Stairwells are impassable for most wheeled platforms, motivating the development of this behavior for our uniquely mobile, legged robot. This implementation uses an RGBD camera for stair acquisition, which offers several advantages over a previously documented detector based on a laser range finder, including significantly reduced acquisition time. This semi-autonomous behavior uses a human driver to provide steering input to the robot, while the transitions to and from the stair climbing gait are entirely handled by the robot. Further automation of the building exploration task would require a mapping algorithm and higher level planner, which are out of the scope of this report. The sensor package used here allows for considerable expansion of this behavior, including the aforementioned autonomy and on-stair obstacle avoidance. This work is applicable to tasks including building exploration in hazardous environments and repetitive patrolling of multiple floors.

9468-11, Session 2

Stabilization and agility quantification of a flexible-spine bounding quadruped model

Katie Byl, Tom Strizic, Univ. of California, Santa Barbara (United States); Jason L. Pusey, U.S. Army Research Lab. (United States)

One goal in developing legged robot systems is to provide a high degree of agility. Intuitively, being agile means that future states (i.e., position and velocity variables defining snapshots of the dynamic robot as it moves) are not deterministically pre-ordained and can instead be controlled to a high degree. For example, a robot that repeats a constant, low-level gait sequence arguably lacks agility, no matter how robust it is to terrain variability. In this work, we introduce two related concepts of agility: "many-to-one" and "one-to-many" control authority. By many-to-one, we mean that a system should be capable of arriving at the same final state (e.g., landing at the far side of a ditch-like obstacle) from a large set of initial conditions; similarly, the system should be capable of recovering from many different perturbations to return back to one particular, nominal gait.

As a complementary notion, one-to-many agility implies that a robot starting at one particular initial condition (e.g., sitting at rest) should be able to reach many different states in a characteristic time, and that it should do so accurately.

In this work, we present a 4-link planar, bounding, quadruped model with compliance in its legs and spine and design five low-level gait controllers. In this planar model, a single link represents the pair of back legs, two links represent a flexible spine, and the final link captures both front legs. The system is highly underactuated, with only one active hip torque available for control when only one leg link is in contact with the ground. Our low-level gait control uses the stance leg hip torque to drive the overall body dynamics to follow a desired, time-based reference trajectory using a simple proportional plus derivative (PD) controller. We discuss intuitive design of the low-level control briefly, but our primary focus is on developing a family of such controllers that facilitate switching control and on methods to develop intelligent high-level switching policies to improve agility.

This work extends our previous methods on meshing hybrid dynamic systems. A similar optimization framework both generates switching policies to increase stability after perturbations compared with any single gait control and finds the set of n-step reachable states. Solutions to these problems also yield new metrics quantifying "agility" for legged robots by quantifying the "volumes" of initial condition states for the many-to-one (ditch-jumping) problem and of final achievable states in the one-to-many problem formulation.

9468-12, Session 4

UAV field demonstration of social media enabled tactical data link

Christopher C. Olson, Andrew J. Newman, Da Xu, Sean R. Martin, Jonathan C. Castelli, Johns Hopkins Univ. Applied Physics Lab., LLC (United States)

This paper addresses the problem of enabling Command and Control (C2) and data exfiltration functions for missions using small, unmanned, airborne surveillance and reconnaissance platforms operating autonomously and clandestinely. The authors demonstrated the feasibility of using existing commercial wireless networks as the data transmission infrastructure to support Unmanned Aerial Vehicle (UAV) autonomy functions such as transmission of commands, imagery, metadata, other belief data, and multi-vehicle coordination messages. The authors developed and integrated a C2 Android application for ground users with a common smart phone, a C2 and data exfiltration Android application deployed on-board the UAVs, and a web server with database to disseminate the collected data to distributed users using standard web browsers. The authors performed a mission-relevant field test and demonstration in which operators commanded a UAV from an Android device to search and loiter; and remote users exploited imagery, video, and metadata via web server to identify and track a target. Social media served as the tactical data link for all command messages, images, videos, and metadata during the field demonstration. Imagery, video, and metadata were transmitted from the UAV to the web server via multiple Twitter, Flickr, Facebook, YouTube, and similar media accounts. The web server reassembled images and video with corresponding metadata for exploitation by distributed users. The UAV autopilot communicated with the on-board Android device via on-board Bluetooth network.

9468-13, Session 4

Fuel Cell powered small unmanned aerial systems (UASs) for extended endurance

Deryn D. Chu, Zachary Dunbar, Rongzhong Jiang, U.S. Army Research Lab. (United States); Kyle Grew, Joshua McClure, Army Research Laboratory (United States)

Small unmanned aerial systems (SUASs) have been used for military applications. They also have potential for commercial applications. For military applications, these systems provide valuable intelligence, surveillance and reconnaissance (ISR) capabilities for units at the infantry battalion and company level. The SUASs are light-weight, man-portable, hand-launchable, and capable of carrying payloads. SUASs can be broadly classified by their performance characteristics such as engine type, weight, speed, and endurance. Currently, small UASs are powered by lithium-ion or lithium polymer batteries; however, the flight endurance is usually limited and requires frequent battery replacement. The long endurance flight

time for SUASs have been demonstrated through propane fueled fuel cell systems. In this presentation, we address propane fueled solid oxide fuel cell systems (SOFC) to power a ~20lbs unmanned aerial system for 8hrs (4x improvements over state-of-the-art battery).

9468-14, Session 4

Tactical 3D model generation using structure-from-motion on video from unmanned systems

Joshua D. Harguess, Mark Bilinski, Kim B. Nguyen, Darren N. Powell, Space and Naval Warfare Systems Ctr. Pacific (United States)

Unmanned systems have been cited as one of the future enablers of all the services to assist the warfighter in dominating the battlespace. The potential benefits of unmanned systems are being closely investigated -- from providing increased and potentially stealthy surveillance, removing the warfighter from harm's way, to reducing the manpower required to complete a specific job. In many instances, data obtained from an unmanned system is used sparingly, being applied only to the mission at hand. Other potential benefits to be gained from the data are overlooked and, after completion of the mission, the data is often discarded or lost. However, this data can be further exploited to offer tremendous tactical, operational, and strategic value. To show the potential value of this otherwise lost data, we designed a system that persistently stores the data in its original format from the unmanned vehicle and then generates a new, innovative data medium for further analysis. The system streams imagery and video from an unmanned system (original data format) and can then constructs a 3D model (new data medium) using structure-from-motion. The 3D generated model provides warfighters additional situational awareness, tactical and strategic advantages that the original video stream lacks. We present our results using simulated unmanned vehicle data with Google Earth providing the imagery as well as real-world data, including data captured from an unmanned aerial vehicle flight.

9468-15, Session 4

Aircraft path planning for optimal imaging using dynamic cost functions

Gordon Christie, Haseeb R. Chaudhry, Kevin Kochersberger, Virginia Polytechnic Institute and State Univ. (United States)

Unmanned aircraft development has accelerated with recent technological improvements in sensing and communications, which has resulted in an "applications lag" for how these aircraft can best be utilized. The aircraft are becoming smaller, more maneuverable and have longer endurance to perform sensing and sampling missions, but operating them aggressively to exploit these capabilities has not been a primary focus in unmanned systems development. This paper addresses a means of aerial vehicle path planning based on the A* method with dynamic cost functions to provide a realistic optimal path in acquiring imagery for structure from motion (SfM) reconstructions. This method will allow SfM reconstructions to occur accurately and with minimal flight time so that the reconstructions can be executed efficiently.

Current methods of obtaining imagery for SfM reconstructions do not attempt to find optimal camera pose to maximize image value. The method presented here considers cost functions in image pose to guide an aircraft during an imaging mission. Furthermore, the aircraft dynamics are incorporated into the path planning algorithm as dynamic cost functions to create optimal imaging paths in minimum time. Simulations for urban environment mapping are shown.

9468-16, Session 4

Cloud-Based Distributed Control of Unmanned Systems

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Unmanned systems have become integral in modern warfare by enabling warfighters to efficiently and safely execute dangerous missions. The increasing use of unmanned systems have led to vast amounts of data collected from sensors placed on unmanned vehicles. As a result, many systems have been developed to provide the tools needed to perform one of the following functions: controlling the unmanned vehicle or analyzing and processing the sensory data from unmanned vehicles. These systems are often disparate from one another limiting the ability for users to work and collaborate together. Space and Naval Warfare Systems Center Pacific (SSC Pacific) envisioned the potential benefits from "operators" – users who control unmanned systems and "analysts" – users who process and analyze data collaborating together as one team, and created the "UxV to the Cloud via Widgets" project. "UxV to the Cloud via Widgets" was architected to provide "operators" and "analysts" a collaborative framework that enabled distributed control of unmanned systems, sensor data cloud storage and sharing, and post-mission analysis tools within a web browser. This paper focuses on how the "UxV to the Cloud via Widgets" system was designed and implemented by leveraging the following technologies: Data Distribution Service (DDS), Accumulo, and Ozone Widget Framework (OWF).

9468-17, Session 5

Construction robots for Mars

Douglas W. Gage, XPM Technologies (United States)

The first humans on Mars will rely on robots, not replace them. Robots and other unmanned systems will play many critical roles in support of a human presence on on Mars, including surveying candidate landing sites, locating ice and mineral resources, establishing power, communications, and navigations infrastructure, performing construction tasks, and transporting equipment and supplies. Robots serving in these different roles will require different capabilities. This paper considers the technologies and capabilities required for a system of robots that could be employed to construct an underground base on Mars: defining a candidate baseline structure (tunnel), scoping the excavation and other tasks required to create it, defining relevant tradeoffs between numbers of robots and bot strength/size/power, discussing robotic functional and performance capabilities, and considering some approaches to providing the required power, control, navigation, and communications.

9468-18, Session 5

Research for a multi-modal mobility and manipulation propulsion core

Harris L. Edge, U.S. Army Research Lab. (United States); Jason Collins, Engility (United States)

This project is part of an overall effort within the U.S. Army Research Laboratory to develop technologies to allow unmanned aerial systems (UAS) to fly safely and perform work in the near Earth environment. One aspect of this effort is to perform research for airborne manipulation in which the aircraft is to interact with the environment. To do this, a research aircraft has been designed with a strong light weight frame and thrust vectoring propulsion. This paper will document design, characterization of the platform, and initial flight control algorithm development. At the basic research level, this platform will help expand the scope of whole body manipulation research. There are a number of issues in the study of airborne

manipulation. Developing the controls for managing the attitude and position of an aircraft that has a shifting center of gravity and force exerted on it through interaction with the environment will be difficult. Some of the difficulty may be alleviated through purposeful and intelligent design of the vehicle and the manipulators used to interact with the environment. For example, the aircraft has been specifically designed to interact with vertical surfaces. Safe navigation of human-habitable 3-D environments has also been addressed through design and will be further explored using the capabilities of the platform in future research. At the present, the military primarily employs UAS for reconnaissance. The primary benefit of this research is to enable UAS to also perform a physical task at its destination. This will greatly expand the types of missions that UAS can perform. This project would seek to advance the state of the art by implementing controls for dexterous manipulation during flight and/or when a high percentage of a vehicle's weight is supported by an air-based propulsion system. Dexterous manipulation for UAS may be helpful for a number of scenarios in which interaction with the environment is beneficial such as robust landing techniques, bracing to enable a mobility maneuver near a surface, emplacement and retrieval of objects, physical inspection in hard to reach and dangerous locations, and gathering physical evidence, etc. In addition it may be used to exchange materiel with an unmanned ground vehicle.

9468-19, Session 5

Automatic pose sensing for an IED-detecting dog

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The Office of Naval Research's Improvised Explosive Device (IED)-Detector Dogs (IDDs) program trains and fields dogs that perform off-leash, detect potential IEDs through their sense of smell, and perform a specific behavior to indicate a possible IED detection. This behavior is noticed by the dog handler, who confirms if it's a probable IED, determines the location, and forwards it back to base or to explosive ordnance disposal (EOD) teams via radio, email, or after-action reports.

To improve the speed and accuracy of this reporting process and better integrate it with the EOD team's robotic disposal operation, SPAWAR Systems Center Pacific has designed and prototyped an electronic dog collar that automatically tracks the dog's location and attitude, detects the indicative behavior, and automatically records the data. To account for the differences between dogs, a 5-minute training routine can be executed before the mission to establish initial values for the K-mean Clustering algorithm that classifies the dog's behavior.

The recorded data include GPS location of the suspected IED, the path the dog took to approach the IED, and a video clip surrounding the detection event. The dog handler confirms the data before forwarding it on to the EOD team. The EOD team uses the video clip to better identify the IED and for awareness of the surrounding environment before they arrive at the scene. Before the robotic bomb-disposal operation commences at the site, the location and path data (which are supplied in a format understandable by the next-generation EOD robots—the Advanced EOD Robotic System) can be loaded into the robotic controller to automatically guide the robot to the location of the IED.

This paper describes the project, with emphasis on the dog-collar hardware, behavior-classification software, and testing.

9468-20, Session 5

Incremental learning in trust-based vehicle control

Dariusz G. Mikulski, Robert E. Karlsen, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

In many multi-agent systems, robots within the same team are regarded as being fully trustworthy for cooperative tasks - usually due to the complexity involved in producing robust, autonomous multi-robot solutions. However, since military robots have unique vulnerabilities related to the threat of cyber attacks, the assumption of trustworthiness may not only increase the risk of mission failure, but also endanger the lives of friendly forces. In prior work, we addressed this issue by using RoboTrust to dynamically adjust to observed behaviors or recommendations, in order to mitigate the risks of illegitimate behaviors. However, at present, RoboTrust can only respond to observed performance and does not dynamically learn agent behavior. As such, in this paper, we incorporate an adaptive agent-specific bias into the RoboTrust algorithm that modifies its trust dynamics. This bias is learned incrementally from agent interactions, allowing good agents to benefit from faster trust growth and slower trust decay and bad agents to be penalized with slower trust growth and faster trust decay. We then integrate this new trust model into a trust-based controller for decentralized autonomous convoy operations and evaluate its performance in the presence of malicious vehicles during a mission.

9468-21, Session 5

Differences in cyber security considerations for remotely piloted and autonomous unmanned aerial vehicles

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

Unmanned aerial vehicles can utilize a variety of control methodologies. On one end of the spectrum are vehicles that are largely manually controlled with a human operator remotely piloting the aircraft in a manner similar to how an onboard pilot would fly an aircraft. This type of UAV will generally have an autonomous system to respond to link failure (and bring the aircraft back to the last point of communications or, failing that, to a designated location). On the other end of the spectrum are UAVs that are largely autonomous where controllers provide high-level tasking but do not make the maneuver-by-maneuver decisions of piloting the craft. This paper considers the differences between securing these two different types of UAV systems. It presents two different system architectures (one for the autonomous and one for the remotely piloted system) and discusses what types of security considerations are present.

Using these two architectures, prospective security and assurance strategies for the two systems are presented and contrasted. Need analysis for the security/assurance decisions is presented and discussed. A particular focus is paid to the assurance and security considerations of the autonomous system. This includes identifying multiple classes of prospective vulnerability, based on considering system operating assumptions. From this, one particular class of attack – of particular interest – that attempts to exploit the confusion of the autonomous control system to produce desired actions is considered. A variety of prospective strategies for hardening the control software against this type of attack, as well as responses to it are discussed, before concluding.

9468-22, Session 5

Design and experimental validation of a simple controller for a multi-segment magnetic crawler robot

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A novel, multi-segmented magnetic crawler robot has been designed for ship-hull inspection. In its simplest version, passive linkages that provide two degrees of relative motion connect front and rear driving modules, so the robot can twist and fold. This permits it to navigate over surface discontinuities while maintaining adhesion with the hull. During operation,

the magnetic crawler receives forward and turning velocity commands from either a tele-operator or high-level, autonomous control computer. A low-level, embedded microcomputer handles the commands to the driving motors.

This paper presents the development of a simple, low-level, leader-follower controller that permits the rear module to follow the front module. The kinematics and dynamics of the two-module magnetic crawler robot are described. The robot's geometry, kinematic constraints and the user-commanded velocities are used to calculate the desired instantaneous center of rotation, and the corresponding central linkage angle necessary for the back module to follow the front module when turning. The commands to the rear driving motors are determined by applying PID control on the error between the desired and measured linkage angle position. The controller is designed and tested using Matlab Simulink. It is then implemented and tested on an early two-module magnetic crawler prototype robot. Results of the simulations and experimental validation of the controller design are also presented.

9468-23, Session 5

The role of C4ISR (command, control, communications, computers, intelligence, surveillance and reconnaissance) in expedited deployment of autonomous UGV's

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The new program described has 4 major themes:

a. Use of new sources of superior a priori information obtained by integrating the robot with the "Tactical Network" through which a more detailed representation of the robot's "world model " can be built and enriched through the mission, this integration with the network will also make available the data gathered by the bots to a much larger tactical audience.

b. Provide autonomous robots a new option to send and receive highly compressed, very low data rate information, beyond line of sight to the autonomous system supervisor who can attempt to "extract" a robot from a problematic mobility location where it is computationally "stuck" as a viable alternative to "Mission End."

c. Integrate b. (above) to appropriate, existing BLOS communications link.

d. Evaluate new sensing/processing options to enable an increase in robot speeds expanding the range of new applications enabled by this improved match with unit "optempo".

9468-24, Session PThu

Open Space Box: communication to support big data in orbit

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

Big Data is the reality created by the fusion of computers and progressively improving sensor technology. The data created by the use of sensors, scanners and in general, which is needed for a mission or operations, is growing dramatically, on an annual basis.

The idea of denormalization applies to all sorts of data now. Open Space Box presents a novel model of communications to support future data transmission needs. This Big Data processing technique facilitates the analysis, storage and processing for needs that we presently have and potential future needs. Open Space Box provides direct NoSQL to NoSQL data transmission, allowing a single virtual database to span multiple orbital and terrestrial locations.

The autonomic nature and pervasive (shared between all spacecraft) data context enables a single factual view. Thus, from a user's or application developer's perspective it doesn't matter (except, of course, for the local hardware, sensing capabilities and other resources available) whether the application runs within a single space craft or across a few in similar orbitd. Moreover, excepting sensing requirement foufilment, it does not matter, what the trajectories of these spacecraft are. It is a known fact a Nano Satellite or CubeSat has rather limited lifespan. In addition to scheduled mission conclusion point, an unknown peril, such as a collision with space debris or some other object might terminate the mission of this small space craft or damage or destroy the equipment used to capture, process and transmit data.

Communication to and from a small spacecraft can be at an extremely slow Baud rate, means both sending and receiving any communication will take some time to egress and ingest, the ETL (Extract, Transform & Load) tools designed to transmit and receive data needs to have a base protocol, which is flexible. The Open Space Box (OSB) model provides this base for smaller spacecraft to provide users data in a fashion that is pervasive within satellites as well as the ground stations. It also autonomically distinguishs between data streams and disseminates relevant information to the related end users. Request and Response messages are sent in batch mode and communications are done using MapReduce.

9468-25, Session PThu

Stealth Technology: the potential to make the visible, invisible

Laura Samso Pericon, Consultant (Spain)

Sun Tzu broadly defined the art of war as stealth: "O divine art of subtlety and secrecy! Through you we learn to be invisible, through you inaudible; and hence we can hold the enemy's fate in our hands." to conquer the enemy without their even realizing it. Stealth or 'low-observable' technology, is currently defined as a complex blend of radar, infrared (IR), visual, acoustic signature, radio frequency (RF) emissions reduction and other techniques. It is the potential to make something visible invisible, not detectable.

Unmanned stealth aircrafts could be used for different purposes such terrorism incident prevention and recovery. After the 9/11, there was a campaign against terrorist organizations and regimes resulting in a measure that authorized the use of the necessary force, in the US, to prevent any international terrorism.

Some of the first developments began in the early 1900s when Germany and the URSS (USSR) built planes using transparent materials such emaillit, cellon, rodoid. However, the advent of radar during WWII changed the rules and led to the development of new stealth technologies: the Horten Ho 229. The first manned aircraft with pure stealth design was the Defense Advanced Research Projects Agency (DARPA)/US Air Force (USAF) research program code-named HAVE BLUE (1973) that resulted in the Lockheed F-117A fighter.

New developments in optics (metamaterials) could lead to an operative 'nearly perfect lens', enhancing system target tracking capabilities and geospatial data collection capabilities; hypersonics research being conducted under DARPA would allow a responding nationality to be anywhere in the world in less than 1 h. Some ongoing unmanned stealth projects are the X-47B, the Taranis aircraft from UK, among others.

This paper will cover how this technology could help different law enforcement and intelligence in areas such terrorism.

9468-27, Session PThu

Mathematical modeling and system identification of an unmanned aerial system

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Unmanned aerial systems (UAS) are becoming increasingly visible in our daily lives; and range in operation from search and rescue, monitoring hazardous environments, and to the delivery of goods. One of the most popular UAS are based on a quad-rotor design. These are typically small devices that rely on four propellers for lift and movement. Quad-rotors are inherently unstable, and rely on advanced control methodologies to keep them operating safely and behaving in a predictable and desirable manner. The control of these devices can be enhanced and improved by making use of an accurate dynamic model. In this paper, mathematical models and system identification techniques are used to create and study an accurate system model for a quad-rotor. Other popular models are also compared and discussed.

9468-28, Session PThu

Establishing a disruptive new capability for NASA to fly UAV's into hazardous conditions

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9469-1, Session 1

Correction of active space telescope mirror using woofer-tweeter adaptive optics

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Future large aperture space telescopes may use lightweight correctable active mirrors.

The Naval Postgraduate School's Segmented Mirror Telescope (SMT) test bed uses 1-meter silicon carbide (SiC) active mirror segments to form a six-segment deployable 3-meter telescope. The active segments suffer from residual surface figure errors after a correction is applied. This research proposes using woofer-tweeter adaptive optics to actively compensate for segment surface figure error, and external disturbances. An additional deformable mirror is added to the SMT test bed to include two deformable mirrors in the optical path. This optical configuration can reduce manufacturing and testing cost by reducing stringent optical performance requirements of the active primary segments. The addition of another deformable mirror also provides a robust correctable design.

The residual surface error of the SMT segment primarily consists of print-through and dimpling caused by the manufacturing process. This results in an uncorrectable high spatial frequency surface figure error. A woofer-tweeter architecture can improve the surface figure error of segmented mirror by increasing stoke and actuator density. Additionally the woofer and tweeter can work together to correct for external disturbances like thermal drift and structural disturbances of the large mirror.

The large active SMT segment is configured as the woofer, and a small continuous micro-electro-mechanical system (MEMS) deformable mirror is configured as the tweeter. An interferometer measures the surface figure error and provides feedback to a closed loop woofer-tweeter constrained optimization control laws. Closed loop surface figure error improvement is demonstrated by simulation and experiment. Simulation and experimental results are presented.

9469-2, Session 1

Adaptive, realtime spectral imaging system with a digitally programmable matched filter function

J. Daniel Newman, Andrew P. Sacco, Angela M. D'Orazio, Eskandar Ensafi, Exelis Geospatial Systems (United States); Yves Conturie, Exelis Inc. (United States); Steven Chien, Jet Propulsion Lab. (United States); Marek Kowarz, MicroAdventure Technologies LLC (United States); Paul P. K. Lee, George S. Brown, Exelis Geospatial Systems (United States); Ralph C. Short, Jeffrey Czajka, ITT Exelis (United States)

We describe a novel MEMS display-based imaging spectrometer that synthesizes and projects optically matched filtered line images onto a high speed scanning TDI array via a digitally programmable filter generation method. The spectrometer operates in the VNIR/SWIR optical bands with a 5000:1 contrast ratio and has >1MHz optical switching speed capability. Detailed image science simulations have been performed validating that this technology approach is capable of achieving comparable target detection performance to best in class hyperspectral imaging while simultaneously providing over 100x increase in area coverage rate with a 220x decrease in real-time computational processing requirements compared to conventional HSI. The simulation approach utilizes real scene data from three different hyperspectral sensors: ACES-Hy, SpecTIR, and AVIRIS. In the implementation modeled, the matched filter detection is derived from simultaneously capturing positive and negative matched filter images on a dual linear TDI array and subsequently subtracting and thresholding. The TDI arrays are co-located on the same die substrate which provides extremely precise spatial and temporal alignment with a small time delay and stable calibration.

9469-3, Session 1

Characterizing point spread function (PSF) fluctuations to improve resident space object detection (RSO)

Tyler Hardy, Stephen C. Cain, Air Force Institute of Technology (United States)

This research paper deals with methods for improving the performance of Electro-optical detection systems designed to find Resident Space Objects (RSOs). Some methods for detecting RSOs rely on accurate knowledge of the system Point Spread Function (PSF). The PSF is a function of the telescope optics, the atmosphere, and other factors including object intensity and noise present in the system. Due to the random photon arrival times any observed data will contain Poisson noise. Assuming that other noise sources such as dark current and readout noise do not contribute significantly, the final source of intensity fluctuations in the data is the atmosphere. To quantify these fluctuations, an optical model of a telescope system is developed and its PSF is simulated. In a long exposure image, the effects of the atmosphere are well characterized with the long exposure atmosphere Optical Transfer Function (OTF). In contrast, a short exposure image does not average the fluctuations as effectively. To model the atmosphere, random phase screens with Kolmogorov statistics are added to the optical model to observe PSF fluctuations in short exposure telescope data. The distribution of the peak intensity is analyzed for varying exposure times and atmospheric turbulence strengths. This distribution is combined with the Poisson random arrival times of photons to create a combined model for received data, which is then used to design a new detection algorithm. The performance of the new space object detection algorithm will be compared to a traditional algorithm using simulated and measured telescope data.

9469-4, Session 1

High-resolution infrared detector and its electronic unit for space application

Mustapha Meftah, LATMOS (France); Franck Montmessin, CNRS - LATMOS (France); Oleg Korablev, Alexander Trokhimovskiy, IKI (Russian Federation); Germain Poiet, CNRS - LATMOS (France); Jean-baptiste Bel, SOFRADIR (France)

High-resolution infrared detector is used extensively for military and civilian purposes. Military applications include target acquisition, surveillance, night vision, and tracking. Civilian applications include, among others, scientific observations. For our space systems, we want to use the products developed by Sofradir company. Thus, we have developed a space electronic unit that is used to control the high-resolution SCORPIO-MW-K508 infrared detector, which has a format of 640x512 and pixel pitch of 15 μm. The detector within microelectronics based on infrared mid-wave

(MW) complementary metal oxide semiconductors (CMOS) uses a micro-cooler (K508) in order to keep its temperature around 100 K. The standard wavelength range (3 to 5 ?m) is extended to the 2 to 5 ?m wavelength range thanks to adaptation of the optical interface of the detector and with an antireflection coating. With our electronic system, we can acquire 3 images per second. To increase the signal to noise ratio, we have the opportunity to make a summation of 15 frames per image. Through this paper, we will describe the space electronic system that we have developed in order to achieve space observations (e.g. Atmospheric Chemistry Suite package for ExoMars Trace Gas Orbiter).

9469-5, Session 1

Anomalous cases of astronaut helmet detection

Chester Dolph, NASA Langley Research Ctr. (United States) and Old Dominion Univ. (United States); Andrew J. Moore, NASA Langley Research Ctr. (United States); Matt Schubert, NASA Langley Research Ctr. (United States) and Christopher Newport Univ. (United States); Glenn Woodell, NASA Langley Research Ctr. (United States)

An astronaut's helmet is an invariant, rigid image element that is well suited for identification and tracking using current machine vision technology. Future space exploration will benefit from the development of astronaut detection software for search and rescue missions based on EVA helmet identification. However, helmets are solid white, except for metal brackets to attach accessories such as supplementary lights. We compared the performance of a widely used machine vision pipeline on a standard-issue NASA helmet with and without affixed experimental feature-rich patterns. Performance on the patterned helmet was far more robust. We found that four different feature-rich patterns are sufficient to identify a helmet and determine orientation as it is rotated about the yaw, pitch, and roll axes. During helmet rotation the field of view changes to frames containing parts of two or more feature-rich patterns. We took reference images in these locations to fill in detection gaps. These multiple feature-rich patterns references added substantial benefit to detection, however, they generated the majority of the anomalous cases. In these few instances, our algorithm keys in on one feature-rich pattern of the multiple feature-rich pattern reference and makes an incorrect prediction of the location of the other feature-rich patterns. We describe and make recommendations on ways to mitigate anomalous cases in which detection of one or more feature-rich patterns fails. While the number of cases is only a small percentage of the tested helmet orientations, they illustrate important design considerations for future spacesuits. In addition to our four successful feature-rich patterns, we present unsuccessful patterns and discuss the cause of their poor performance from a machine vision perspective. Future helmets designed with these considerations will enable automated astronaut detection and thereby enhance mission operations and extraterrestrial search and rescue.

9469-6, Session 1

Program technical baseline framework for future space systems: a combined DoD acquisition, OSA and integrated program management perspective *(Invited Paper)*

Tien M. Nguyen, Andy T. Guillen, Sumner S. Matsunaga, The Aerospace Corp. (United States)

The U.S. Department of Defense (DoD) recently focused on the modernization (Ref. 1) and development of existing and future space systems, respectively, using mandated DoD and Congressional Acquisition reform initiatives (Ref. 2) to improve acquisition efficiency. The initiatives impose three key requirements on the development of future space systems, including making affordability a requirement, increasing competition, and decreasing the time it takes to acquire a system. On the other hand, as indicated in the Space Modernization Initiative (SMI) Strategy (Ref.1), the modernization of existing space systems shall meet three strategic objectives (Ref. 1), namely, design for low Life Cycle Cost (LCC) for affordability, provide desired system capability to meet warfighter needs, and achieve resiliency to operate in contested environments.
In order to meet both strategic objectives and acquisition initiatives, a solid Program Technical Baseline Framework (PTBF) will be required to enable the government and industry partners to effectively manage these developments; improving the basis for competition, assisting government source selection authorities to effectively select among proposed technical solutions, and enabling government-industry partners to effectively manage the system life cycle through development, operations, and sustainment.

The proposed PTBF provides a framework to show how the technical baseline can be generated from the key program components (Ref. 3) using the Integrated Program Management (IPM) approach for integrating the program components with System Engineering (SE) process/tools, SE Cost tools, DoD Architecture Framework (DoDAF) tools, Open System Approach (OSA) process/tools, Risk Management process/tools, Critical Chain Program Management (CCPM), and Earned value Management System (EVMS) process/tools. Based on the proposed framework, the paper provides a matrix that captured the required tools/processes vs. technical features for a "good" reference U.S. DoD "owned" technical baseline. In addition, the paper also discusses the impacts of U.S. DoD acquisition system and the Joint Capabilities Integration and Development System (JCIDS) process on the generation of a program technical baseline, and describes how Open System Approach (OSA) and IPM can help U.S. DoD achieve acquisition reform and system modernization requirements.

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Ref.3: Key program components include Program Requirements, System Architecture Design, Program Risks, Program Cost, and Program Schedule.

9469-7, Session 2

Towards an integrated defense system for cyber security situation awareness

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Computer and communication technologies have given rise to today's worldwide social, business, military, and commercial networks. These networks are vulnerable to various types of cyber-attacks, which necessitates and urgent need for cyber security. Defending against these cyber-attacks requires network security situation awareness through distributed collaborative monitoring, detection, and mitigation. In this paper, we demonstrate an integrated defense system for conducting Cyber Situation Awareness (CSA). Our developed CSA system consists of distributed passive and active network sensors designed to effectively capture suspicious information associated with cyber-attacks, effective detection algorithms to accurately detect cyber-threats, and network actors to rapidly mitigate cyber-attacks. Particularly, passive network sensors can be deployed at both end-hosts and network nodes to capture activities associated with cyber-attacks and active network sensors can interact with cyber-attacks directly and capture the insightful information associated with attacks (e.g., malware signatures). Based on collected data from network sensors, we develop effective machine learning based detection techniques to detect cyber-attacks accurately. To mitigate cyber-attacks, network actors deployed at both end-hosts and network nodes will dynamically use updates from detection algorithms and block cyber-attacks. Finally, we demonstrate scenarios to show the effectiveness of our integrated defense system.

9469-8, Session 2

Internet threat monitoring (ITM) against localization attack using random delay addition

Sixiao Wei, Dan Shen, Intelligent Fusion Technology, Inc. (United States); Wei Yu, Chao Lu, Towson Univ. (United States); Erik Blasch, Khanh Pham, Air Force Research Lab. (United States); Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

There are a variety of dangerous and widespread threats (e.g., botnet and malware propagation) over cyber space. To deal with cyber-attacks, the deployment of collaborative monitoring and defense systems over the global Internet is important. Internet Threat Monitoring (ITM) is one kind of defense system, which has been widely deployed to detect and characterize dangerous Internet global threats such as botnet and malware propagation.

Nonetheless, the effectiveness of ITM systems largely depends on the confidentiality of their monitor locations. The reason is that if an adversary discovers the internet protocol (IP) addresses covered by network sensors, it can easily avoid the detection by bypassing the managed/monitored IP addresses and directing attacks to the much larger space of unmonitored IP addresses. Pragmatically, the ability of identifying network sensor IP addresses from sensor traffic reports has important implications to the successful deployment of network sensor based defense systems. A cyber network defensive infrastructure must detect and mitigate various cyber threats. To improve the security of ITM systems, we have investigated the vulnerability of the defense system, which enables the adversary to identify the IP addresses of detection sensors. Using a frequency based modulation technique with both time and space hopping (FH) effectively achieved a high attack accuracy and invisibility [1].

We extend the FH technique to defend against attacks and make the ITM system secure by using countermeasures. In this paper, we present a novel random delay addition (RDA) technique that significantly reduces the accuracy, efficiency, and secrecy of ITM localization attacks. RDA first identify network protocol and analyze initialized preamble signal to ensure that all systems are interpreting the start of the information transfer correctly. Then it efficiently embeds a randomized time sequence to background traffic when monitors are uploading traffic data to a data center. As a result, it challenges an adversary to recognize and recover its probing signal. RDA uses countermeasures to cause an intruder to mistakenly identify the location of the deployed sensors. Furthermore, we derive closed formulae for the performance analysis of the RDA technique and conduct extensive simulations. Results validate our theoretical findings and demonstrate that RDA reduces the accuracy and invisibility of localization attack.

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9469-9, Session 3

Quantum key distribution for QoS guarantee in satellite networks

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Quantum-based techniques have attracted significant research attention because of its unique advantages on satellite communications, especially for security problem. Security guarantee is one of the most important requirements in QoS-driven 3D satellite networks. 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. Although the QKD method can ensure the absolute security transmission over 3D satellite networks, it imposes many new implementation challenges due to the various limitations on quantum communication over long distances via 3D free space, including quantum channel attenuation, photon-state disruption and vulnerability to noise/interference, laser-beam widening, and constrained security-key generation rate. These problems get even more challenging when QoS provisioning is required for the applications over the 3D satellite networks. To overcome the aforementioned difficulties, we propose the framework to efficiently implement the QKD for security guarantees over quantum-repeater-based QoS-driven 3D satellite networks we propose to employ the intermediate nodes to relay the unconditional keys and guarantee the Quantum Bit Error Rate (QBER) for security requirement over 3D satellite networks. We also propose the communication model for QKD security-Quality of Service (QoS) guarantee and an adaptive cooperative routing selection scheme to optimize the throughput performance of QKD-based satellite communications networks. The obtained simulation results verify our proposed schemes.

9469-11, Session 3

Multi-carrier transmission for hybrid radio frequency with optical wireless communications

Gang Wang, Genshe Chen, Dan Shen, Intelligent Fusion Technology, Inc. (United States); Khanh Pham, Erik Blasch, Air Force Research Lab. (United States); Tien Nguyen, Intelligent Fusion Technology, Inc. (United States)

Radio frequency (RF) wireless communication is reaching its capability to support big data rate transmission due to (i) hardware constraints (e.g., silicon processes), software strategies (e.g., information theory), (ii) spectrum availability, and (iii) consumer desire for timely large file exchanges (e.g., big data and mobile cloud computing). The high transmission rate must be kept in pace with the generated huge volumes of data for real-time processing. Integrated RF and Optical Wireless Communications (RF/OWC) could be the next generation transmission technology to satisfy both the increased data rate exchange and the communications constraints. However, with the promising benefits of RF/OWC, challenges still remain to fully develop operational hybrid RF with wireless optical communications such as uniform waveform design for information transmission and detection. In this paper, an Orthogonal Frequency Division Multiplexing (OFDM) transmission scheme, which widely employed in RF communications, is developed for OWC. The traditional high Peak-to-Average Power Ratio (PAPR) in OFDM is reduced to improve system

performance while reducing harmful effects to human. The proposed multi-carrier OFDM waveform is evaluated using a Monte-Carlo ray tracing (MCRT) analyzed channel, which incorporates the effects of cloud and atmospheric turbulence. It demonstrates that Bit Error Rate (BER) performance of our proposed transmission technique outperforms the traditional On-Off Keying (OOK) transmission scheme.

9469-12, Session 3

RFI modeling and prediction approach for SATOPS Applications

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This paper describes our approach for the development of RFI modeling and detection tool for (i) evaluating effectiveness of the existing Telemetry and Tele-Command (T&TC) waveforms employed by civil, commercial and military SATOP centers, and (ii) predicting the impacts of RFI on existing TT&C systems.

Currently, there are many RFI analysis tools available to analyze the impacts of RFI on SATOP systems. Most of RFI tools do not consider the Time Factor (TF) when calculate Bit or Carrier SNR degradation due to interferences. Some RFI tools incorporate TF by incorporating the SATOP schedules along with IPC to identify the blockage due to RFI. These tools have assumed that RFI would increase receivers' noise floors. None of these tools has considered the effects of the RFI on the receiver synchronization loops. Our approach will incorporate (i) the receiver sync loops including carrier and subcarrier tracking, and symbol timing loops, and thereby evaluating the interfering TF at the synchronization loop-level, (ii) statistical technique to estimate the type of interference and predict its impact on the synchronization loops, and (iii) statistical technique to optimize the SNR of the transmitted T&TC signal to overcome the synchronization errors caused by RFI sources.

The approach proposed in this paper will allow the communications designer to predict and evaluate the impacts of RFI on civil, commercial and military SATOP systems. In addition, the proposed approach also allows the designer to estimate the optimum transmitted SNR to maintain a required T&TC Quality-of-Service (QoS) in the presence of both friendly and un-friendly RFI sources.

Note:

RFI = Radio Frequency Interference

SATOP = SATellite OPeration includes Telemetry, Tracking and telecommanding performed by satellite ground control station.

SNR = Signal-to-Noise Ratio

IPC is Interference Protection Criteria recommended by National Telecommunication and Information Administration (NTIA) and International Telecommunication Union (ITU).

9469-13, Session 3

A TDMA MIMO SAR radar for automated position-keeping

Zhonghai Wang, Xingping Lin, Intelligent Fusion Technology, Inc. (United States); Khanh Pham, Erik Blasch, Air Force Research Lab. (United States); Genshe Chen, Dan Shen, Bin Jia, Gang Wang, Intelligent Fusion Technology, Inc. (United States)

This paper presents a TDMA MIMO SAR Radar with a slideable range window for automated position-keeping, which can be applied in Ballistic Missile Submarine (SSBN) escorting, offshore support vessel servicing the deepwater drillship, etc. The MIMO SAR radar sensor predefines a special part of the target (i.e., the drillship, ship or submarine) as the measurement target and does not need special assistant devices/targets installed on the target vessel, so its application is convenient. In the measurement process, the sensor scans the target, forms the target image, in the image detects the measurement target, and then obtains the range and angle of the measurement target. The MIMO SAR radar has N transmitting antennas and M receiving antennas. All transmitting antennas share a transmitter and all receiving antennas share a receiver using switches, thus the system is low cost. The MIMO SAR radar has N·M (at most) effective SAR phase centers, and the azimuth angle resolution is ?_0.5/NM (finest, ?_0.5 is the antenna element's 3dB beamwidth). The transmitter transmits a frequency modulated continuous wave (FMCW) signal, and the receiver only process the signal limited in the beat frequency region determined by the distance from the measurement target to the sensor and the interested measurement target extension. With the sliding range window, the sensor covers a large range, and at the short distance, provides high accuracy measurements.

9469-27, Session 3

Multi-entity Bayesian network for the handling of uncertainties at SATCOM

Xin Tian, Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Kuochu C. Chang, Todd Martin, George Mason Univ. (United States); Tien Nguyen, Intelligent Fusion Technology, Inc. (United States); Khanh Pham, Erik Blasch, Air Force Research Lab. (United States)

No Abstract Available

9469-14, Session 4

A benchmark for vehicle detection on wide area motion imagery

Joseph Catrambone, Ismail Amzovski, Temple Univ. (United States); Erik Blasch, Carolyn Sheaff, Air Force Research Lab. (United States); Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Haibin Ling, Temple Univ. (United States)

Wide area motion imagery (WAMI) has been attracting an inreased amount of research attention due to its large spatial and temporal coverage. An important application includes moving target analysis, where vehicle detection is often one of the first steps before advanced activity analysis. While there are exist many vehicle detection algorithms, a thorough evaluation of them on WAMI data still remains a challenge mainly due to the lack of an appropriate benchmark. In this paper, we address this issue by presenting a new benchmark for wide area motion imagery vehicle detection data. The benchmark is based on the recently available Columbus Large Image Format (CLIF) WAMI dataset and the Temple Resolved Uncertainty Target History (TRUTH) associated target annotation. Trajectory annotations were provided in the original release of the CLIF dataset, but detailed vehicle annotations remain unavailable. In addition, annotations of static vehicles, e.g., in parking lots, are also not identified in the original release. Addressing these issues, we re-annotated the whole dataset with detailed information for each vehicle, including not only its location but its pose and size. We also run detection algorithms on the dataset, and such algorithms can serve as baselines for future research along the line. Together, the baseline methods, truth, images, and metrics constitute the data set.

9469-15, Session 4

Multi-target detection and estimation with the use of massive independent identical sensors

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With the rapid development of sensors, massive sensors are commonly available in practice that can provide us very rich information for a specific task such as target tracking. This paper presents a novel multi-object detection and estimation (MODE) approach for the particular application with a large number of independent identical sensors. The key is the so-called multi-sensor observation-only inference in which unsupervised learning is employed for multi-sensor data fusion. The present solution comprises three primary steps: 1) map all the observations reported from multiple independent identical sensors in the same state space; 2) cluster these observations according to their spatial distribution: the one that concentrate in the same local area correspond to the same target(s) while scattered points will be identified as clutter (and discarded); 3) the observations that are identified to belong to the same target will be fused, generating the estimate of the state via the so-called observation-only (O2) inference.

Taking advantage of massive sensors, the present approach needs neither to assume the target/clutter model nor to know the level of the system noises; the problem of parameter estimation is not involved for the unknown background. Therefore it can handle very challenging scenarios involving with e.g. maneuver/splitting/merging targets, unknown system noises and clutter density, etc. and is computationally fast. To demonstrate the validity and advantage of the proposed approach, simulations will be presented on typical existing models with comparison of the state-of-the-art MODE solutions and on a very challenging maneuver multi-target tracking of unknown background.

9469-16, Session 4

A suborbital IMU test mission

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This paper presents work conducted for a suborbital test flight to characterize an inertial measurement unit's (IMU's) ability to serve as a position determination mechanism in a GPS-denied environment. In particular, this work is seeking to characterize whether the launch disrupts the IMU to such an extent as to render it unusable.

A CubeSat-size payload has been developed for launch on an engine test mission of a suborbital rocket. This rocket will ascend during the burn phase and, after engine cut-off, fall with a parachute back to the ground. It will then be recovered and the data stored therein will be retrieved for assessment.

To assess the utility of the IMU for positioning across a launch, the trajectory of the rocket from launch to termination is plotted utilizing data stored on the onboard IMU/GPS hardware-software system. Google maps will be used to visualize the IMU trajectory relative to the GPS logs; this data will also be compared quantitatively. The data (from both the IMU and GPS) will also be utilized to characterize the performance of the rocket and to demonstrate the efficacy of using an IMU (without a GPS unit) for this type of characterization in the future.

A description of the hardware and software used is provided. A discussion of the data logging mechanism and the onboard and post-flight processing which is required to compare the GPS fixes and IMU-generated positions is presented. The utility of an IMU capable of maintaining position awareness during launch is discussed before concluding with a discussion of follow-on work.

9469-17, Session 5

Review of game theory applications for situation awareness

Erik Blasch, Air Force Research Lab. (United States); Dan Shen, Intelligent Fusion Technology, Inc. (United States); Khanh Pham, Air Force Research Lab. (United States); Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

Game theoretical methods have been used for Space situational awareness (SSA), Cyber situational awareness (CSA), and Intelligence, Surveillance, and reconnaissance situation awareness (ISA). Each of these cases, awareness is supported by sensor estimation for assessment and the situation is determined from the actions of multiple players. Game theory assumes rational actors in a defined scenario; however, variations in social, cultural and behavioral factors include the dynamic nature of the context. In a dynamic-data driven application system (DDDAS), modeling must include both the measurements but also how those models are used by different actors with different priorities. In this paper, we highlight the fundamentals of game theory by reviewing applications to determine the current state of the art and future needs. We highlight the future needs of information technology (e.g., data aggregation, access, and indexing); multiscale analysis (e.g., space, time, and frequency), and software methods (e.g., SOA, cloud computing).

9469-18, Session 5

Pursuit-evasion games with information uncertainties for elusive orbital maneuver and space object tracking

Dan Shen, Bin Jia, Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Erik Blasch, Khanh Pham, Air Force Research Lab. (United States)

This paper develops and evaluates a pursuit-evasion (PE) game approach for elusive orbital maneuver and space object tracking. Unlike the PE games in the literature, where either assume both players have perfect knowledge of the opponents' positions or use primitive sensing models, the proposed PE approach will solve the realistic space situation awareness (SSA) problem with imperfect information, where the evaders will exploit the pursuers' sensing and tracking models to confuse their opponents by maneuvering their orbits to increase the uncertainties, which the pursuers perform orbital maneuvers to minimize. In the game setup, each game player P (pursuer) and E (evader) has its own motion equations with a small continuous low-thrust. The magnitude of the low thrust is fixed and the direction can be controlled by the associated game player. The entropic uncertainty is used to generate the cost functions of game players. The Nash or mixed Nash equilibrium is composed of the directional controls of low-thrusts. Numerical simulations are emulated to demonstrate the performance. Simplified perturbations models (SGP4/SDP4) are exploited to calculate the ground truth of the satellite states (position and speed).

9469-19, Session 5

Distributed sensor management for space situational awareness via a negotiation game

Bin Jia, Dan Shen, Intelligent Fusion Technology, Inc. (United States); Khanh Pham, Erik Blasch, Air Force Research Lab. (United States); Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

Space situational awareness (SSA) is critical to many space missions serving weather analysis, communications, and navigation. However, the number of sensors used in space situational awareness is limited which hinders collision avoidance prediction, debris assessment, and efficient routing. Hence, it is critical to use such sensor resources efficiently. In addition, it is desired to develop the SSA sensor management algorithm in a distributed manner. In this paper, a distributed sensor management approach using the negotiation game (NGDSM) is proposed for the SSA. Specifically, the proposed negotiation game is played by each sensor and its neighboring sensors. The bargaining strategies are developed for each sensor based on negotiating for accurately tracking desired targets (e.g., satellite, debris, etc.) . The proposed NG-DSM method is tested in a scenario which includes eight space objects and three different sensor modalities which include a space based optical sensor, a ground radar, or a ground Electro-Optic sensor. The geometric relation between the sensor, the Sun, and the space object is also considered. The simulation results demonstrate the effectiveness of the proposed NGDSM sensor management methods, which facilitates an application of multiple-sensor multiple-target tracking for space situational awareness.

9469-20, Session 5

Size distribution for orbital debris measured with the NASA-WISE Instrument

Emily Nystrom, Clemson Univ. (United States); Jeremy Murray-Krezan, Air Force Research Lab. (United States)

From December 2009 thru 2011 the NASA Wide-Field Infrared Survey Explorer (WISE) gathered radiometrically exquisite measurements of debris in near Earth orbits. Assuming grey-body emissivity, the apparent size of debris objects may be inferred, adding substantially to the current catalog of known debris. This report describes a general model for debris size distributed near the GEO belt. Linear and nonlinear regression models were fit to data from the WISE orbital debris catalog. We found that our results were statistically different from previously published debris distributions, suggesting the need for updates to collision probability models.

9469-21, Session 5

Enabling direct feedback between initial orbit determination and sensor data processing for detection and tracking of space objects

Bradley Sease, Virginia Polytechnic Institute (United States); Timothy S. Murphy, Georgia Institute of Technology (United States); Brien R. Flewelling, Air Force Research Lab. (United States); Marcus Holzinger, Georgia Institute of Technology (United States); Jonathan Black, Virginia Polytechnic Institute (United States)

This paper presents an automatic Resident Space Object (RSO) detection and tracking scheme operating at the optical system sensor level. We show that continuous RSO tracking can be made more sensitive and robust with an initial orbit estimate generated on-line and in real-time.

The General Electro-Optical DEtection, Tracking, Identification, and Characterization (GEODETICA) software is intended as a pipeline for processing ground or space-based imagery. The tool is composed of several sub-algorithms which process ingested imagery, detect and discriminate RSO's from non-star objects, and associate observations over time. This tool operates on a Kalman filter bank based on linearized image-plane dynamics. Two motion model hypotheses provide initial discriminators for non-star behavior, followed by online computation of the sensor attitude motion. Outliers in the secondary process indicate non-star behavior.

The GEODETICA software reports angle data for likely RSO signals to a secondary tool, the Iterative Constrained Admissible Region Tracker (ICART). The ICART tool initializes a particle filter with an Admissible Region (AR) containing all feasible orbits consistent with the original observation. By using a particle filter, the algorithm provides online orbit determination with a non-Gaussian final distribution. Online orbit knowledge from the ICART process feeds back into the GEODETICA software through a Matched Filter. Based on the preliminary orbital estimate, the software predicts the appearance of the RSO in the next frame. By correlating this predicted RSO optical signature with the next image in sequence, measurements have been taken on objects with SNR nearing the theoretical limit of 0.2 in simulated scenarios. DISTRIBUTION STATEMENT F: Further dissemination only as directed by AFRL/RVSV, 3550 Aberdeen Ave SE, Kirtland AFB, NM 87117-5776, (20140718), or higher DoD authority.

9469-22, Session 5

Space situational awareness applications for radio astronomy assets

Galen Watts, National Radio Astronomy Observatory (United States); John M. Ford, National Radio Astronomy Obseravtory (United States); H. Alyson Ford, National Radio Astronomy Observatory (United States)

The National Radio Astronomy Observatory (NRAO) builds, operates, and maintains a suite of premier radio antennas, including the 100m aperture Green Bank Telescope, the largest fully-steerable antenna in the world. For more than five decades the NRAO has focused on astrophysics, providing researchers with the most advanced instruments possible: large apertures, extremely low-noise receivers, and signal processors with high frequency and time resolution. These instruments are adaptable to Space Situational Awareness (SSA) tasks such as radar detection of objects in near-Earth and cis-Lunar space, high accuracy orbit determination, object surveillance with passive methods, and uplink and downlink communications. We present the capabilities of antennas and infrastructure at the NRAO Green Bank Observatory in the context of SSA tasks, and discuss what additions and modifications would be necessary to achieve SSA goals while preserving existing radio astronomy performance. We also discuss how Green Bank Observatory's surrounding topography and location within the National Radio Quiet zone will enhance SSA endeavors.

9469-23, Session 5

The Joint Space Operations Center (JSpOC) Mission System (JMS) and Advanced Research, Collaboration, and Application Development Environment (ARCADE): a test bed for space situational awareness algorithms *(Invited Paper)*

Jeremy Murray-Krezan, Air Force Research Lab. (United States)

The Joint Space Operations Center (JSpOC) Mission System (JMS) is a modern service-oriented architecture infrastructure with increased process automation and improved tools to enhance Space Situational Awareness (SSA) for the United States and allied Nations. The first installment of JMS has been delivered. The second installment is currently in progress, modernizing much of the JSpOC's core information systems, with final delivery scheduled for 2016. Post 2016, new installments of JMS will continue to provide additional SSA and Command and Control capabilities that will require development of new applications and procedures as well as the exploitation of new data sources with greater agility. Although the general concepts for new JMS capabilities are notionally defined, it is also recognized that significant technical development is needed in order to create the required new applications, procedures, and data sources.

The Advanced Research, Collaboration, and Application Development Environment (ARCADE) was established in 2012 in order to meet the

future needs for new algorithms and procedures for JMS. The purpose of the ARCADE is to: (1) serve as a centralized testbed for all research and development (R&D) activities related to JMS applications, including algorithm development, data source exposure, service orchestration, and software services, and provide developers reciprocal access to relevant tools and data to accelerate technology development, (2) allow the JMS program to communicate user capability priorities and requirements to developers, (3) provide the JMS program with access to state-of-the-art research, development, and computing capabilities, and (4) support JMS Program Office-led market research efforts by identifying outstanding performers that are available to shepherd thru the formal transition process. In addition to providing JMS with a modern test-bed environment, ARCADE is exploring new business processes for how the U.S. acquires and upgrades its operational information systems.

9469-24, Session 6

Economic analysis of open space box model utilization in space craft

Atif F. Mohammad, The Univ. of North Dakota (United States); Jeremy Straub, Univ. of North Dakota (United States)

It is a known fact that the amount of data about space that is stored is getting larger on an everyday basis. However, the utilization of Big Data and related tools to perform ETL (Extract, Transform & Load) applications will soon be pervasive in the space sciences.

We have entered in a crucial time where using Big Data can be the difference (for terrestrial applications) between organizations underperforming and outperforming their peers. The same is true for NASA and other space agencies, as well as for individual missions and the highly-competitive process of mission data analysis and publication. In most industries, conventional opponents and new candidates alike will influence data-driven approaches to revolutionize and capture the value of Big Data archives. The Open Space Box Model is poised to take the proverbial “giant leap”, as it provides autonomic data processing and communications for spacecraft.

We can find economic value generated from such use of data processing in our earthly organizations in every sector, such as healthcare, retail. We also can easily find retailers, performing research on Big Data, by utilizing sensors driven embedded data in products within their stores and warehouses to determine how these products are actually used in the real world. This paper assesses the value that can be gained by utilize similar techniques in space. Following a similar analysis path, we assess the types and amount of data that is being (and could be generated) and the amount that is being actually effectively used. We estimate a value for that data is not currently being processed. From this, we contend that the relative value of utilizing big data techniques (such as Open Space Box) is as pronounced in orbit (if not more so) as on Earth’s surface.

The Open Space Box framework’s Data Recharging Model, for example, can help in the creation of new data products associated with space mission planning and enable data processing onboard spacecraft, which are for research purposes and have no human onboard.

9469-25, Session 6

The effects of developments in the stealth technology, passive radars and optic sensors on the future

Asim Göktas, Turkish War College (Turkey)

There is a cutthroat competition between chase and hunter in nature. The chase want to diagnose the hunter as early as possible, also the hunter want to approach its chase as invisible.

In the same way, this essential principle is valid in the field of warfare. The elements in the field of warfare contiuonusly searching for technological and tactical improvements in order to outmaneuver against each other. In the result of this quest , the crucial changes occured. One of these is the using of air power with the aim of war. The airplanes firstly emerge with 1911 Ottoman-Italy war in warfare scene. In this date, the airplanes are painted various color in order to able approach their targets, the aim of this method is to make difficult the detection of the airplanes by the enemy observer. With the using the airplanes in the field of warfare, the strategic superiority of the assailment? side is decreased by using and evolving the radar system.

As a result of the decreasing superiority of the assailment with the beginning of using radar system , new approaches are looked for. These seekings directed the development of the low observable technology.

In this study, Resource search about the history and the context of the low observable technology is arranged. The based on these information that are obtained, the changes that are generated by this technology in the field of warfare are evaluated by examining operations that low observable technology is used. Finally, low observable technology will be one of the most important elements in the field of warfare in the future. Also, other possible development is making a radical change in present air defense systems, and this change is evaluated that being towards passive radar systems and the development sensor system that monitor optically from space or earth.

9469-26, Session 6

The Thermal Infrared Compact Imaging Spectrometer (TIRCIS): a follow-on to the Space Ultra-Compact Hyperspectral Imager

Sarah T. Crites, Robert Wright, Paul G. Lucey, Univ. of Hawai’i (United States); Jeremy Chan, Univ. of Hawai’i at Manoa (United States); Harold Garbeil, Amber Imai, Eric J. Pilger, Mark Wood, L. Yoneshige, Univ. of Hawai’i (United States)

The Thermal Infrared Compact Imaging Spectrometer (TIRCIS) is a long wave infrared (LWIR, 8-14 microns) hyperspectral imager designed as the follow-on to the University of Hawaii’s SUCHI (Space Ultra Compact Hyperspectral Imager). SUCHI is a low-mass (<9kg), low-volume (10x12x40cm3) LWIR spectrometer designed as the primary payload on the University of Hawaii-built ‘HiakaSat’ microsatellite. SUCHI is based on a variable-gap Fabry Perot interferometer employed as a Fourier transform spectrometer with images collected by a commercial off-the-shelf microbolometer contained inside a 1-atm sealed vessel. The sensor has been fully integrated with the HiakaSat microsatellite and is awaiting launch in 2015. The TIRCIS instrument is based on the same principles but takes lessons learned from SUCHI and applies them to a new design with improvements in spatial resolution, spectral resolution and spectral responsivity. The TIRCIS instrument is based on an uncooled microbolometer array with custom detector coatings to enhance responsivity towards 7 microns. Like SUCHI, TIRCIS utilizes a variable-gap Fabry Perot interferometer to create the spectra, but three different interferometer wedges with varying slopes resulting in spectral resolution ranging from 44 cm-1 to 6.5 cm-1 will be tested to explore tradeoffs between spectral resolution and sensitivity. TIRCIS is designed to achieve 120 m spatial resolution from a theoretical 500 km orbit. It will be used for ground and aircraft data collection but will undergo environmental testing to demonstrate its relevance to the space environment. TIRCIS has been fully designed and is entering fabrication, with an operational instrument to be delivered in April 2015.

Conference 9470A: Display Technologies and Applications for Defense, Security, and Avionics IX

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9470-1, Session 1

Diver's full face mask head-up display using waveguide optical display technology

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Military, public safety, and science divers conduct operations in one of the most extreme environments on the planet. Extremes of depth, temperature, and pressure are routine – as well as extremely poor visibility. Historically, this has been a serious operational and safety limitation since handheld visual displays and gauges can be virtually useless in this environment.

Recently developed near-to-eye (NTE) diver display systems using micro displays and custom designed optical systems have made a positive impact, but they are still very limiting due to their large size, weight, and narrow field-of-view. Transforming the diver's faceplate itself into a see-through head-up display would eliminate the need for externally attached displays and multiple display systems for different sensors, while increasing field-of-view and situational awareness, significantly reducing size, and providing a true augmented reality display capability for divers.

Emerging Waveguide Optical Display Technology holds the promise of being the break-through technology for providing this see-through head-up display capability for divers. Waveguide optical display technology optically couples images from a high resolution micro display into a waveguide optic, translates the image through a series of internal reflections, finally exiting toward the eye resulting in a magnified, see-through virtual display image at a specific distance in front of the diver.

Under a recent international government sponsored program, the Naval Surface Warfare Center-Panama City Division (NSWC PCD) developed a concept prototype binocular see-through head-up display inside a diver's full face mask using waveguide optical display technology.

The paper will describe diver NTE display systems, waveguide optical display technologies, development of the concept prototype, results of diver evaluations, and recommendations for follow-on research and development.

9470-2, Session 1

Augmented reality technology for heads-up, day/night situational awareness for the dismounted soldier

Eric Gans, David C. Roberts, Matthew Bennett, Alberico Menozzi, Herman Towles, James Cook, Applied Research Associates, Inc. (United States)

This paper describes Applied Research Associates' (ARA) recent advances in soldier augmented reality (AR) technology. Our AR technology (ARC4) delivers heads-up situational awareness to the dismounted warfighter, enabling non-line-of-sight team coordination in distributed operations. ARC4 combines compact head tracking sensors with advanced pose estimation algorithms, network management software tools, and an intuitive AR visualization interface to overlay tactical iconic information accurately on the user's real-world view. The technology supports heads-up navigation, blue-force tracking, target handoff, image sharing, and tagging features in the environment. It integrates seamlessly with established network protocols (e.g., Cursor-on-Target) and Command and Control software tools (e.g., Nett Warrior, Android Tactical Assault Kit) and interfaces with a wide range of daytime see-through displays and night vision goggles to deliver real-time actionable intelligence, day or night. We detail current research and development efforts toward helmet-based and handheld AR systems and discuss key metrics used to assess an effective AR experience, including those related to pose estimation, through-sight display, and computer processing. Details of the pose estimation technology include an overview of our data fusion process that incorporates inertial data, magnetometer data, GPS and DTED with real-world imagery to provide measurements of the operator's precise orientation. These measurements leverage mountainous terrain horizon geometry, known landmarks, and sun position, enabling ARC4 to achieve significant improvements in accuracy compared to conventional INS/GPS solutions of similar size, weight, and power. We report recent performance results during outdoor on-the-move operational use cases and describe extensions of the AR technology to immersive training applications.

9470-3, Session 1

Operational feedback on night vision with hyperstereoscopic HMD

Jean-Michel Francois, Thales Avionics S.A. (France); Daniel Maulet, Thales Angénieux S.A. (France); Joel Baudou, Thales Avionics S.A. (France)

The hyperstereopsis design for night vision function has been used for the benefit of a see-through display and several examples of this kind of design have been implemented: TopOwl from Thales, KnightHelm from Baé and Midash from Elbit. Many discussions occur on the usage of hyperstereoscopic system for highly complex operational use and the balance of advantages and drawbacks. This paper will cover hyperstereopsis experience through the TopOwl history from development to full operational use.

During development, emphasis of the see-through advantage shall be the priority and during integration special attention shall be taken for the installation in the cockpit and the visibility through helicopter struts.

Human factors explains several changes in the perception of the world and which adaptation is needed through the training of the pilot. Training has occurred for more than 500 pilots on very different platforms such as Tiger attack helicopter and Caiman NH90 transport helicopter. The synthesis of the use of a hyperstereopsis design with very different users as Marines/Army from more than 16 countries and with very different missions as Reco/Support/Destroy.

Operational use of TopOwl is well known and exists for the more complex missions in different theaters. The comparison between standard Night Vision Goggle and see-through hyperstereopsis Night Vision system is done based on the experience coming from training school process and adaptation of the different pilot trainees and from the experience feedback on three different operational theaters.

9470-4, Session 2

Review and current status of head-mounted display technologies *(Invited Paper)*

Hong Hua, College of Optical Sciences, The Univ. of Arizona (United States)

Head-mounted display (HMD) technologies enable a wide range of applications, from military simulation and training to entertainment and information displays. In this talk, I will provide a review on past and current

technological advancements, with more emphasis on optical see-through HMDs for augmented reality applications. I will demonstrate examples of HMD systems developed in my group based on emerging freeform optics, and discuss key technical challenges and opportunities for future developments.

9470-5, Session 2

Keeping display visibility in outdoor environment

Ariela Donval, Ido E. Dotan, Noam Gross, Eran Partouche, Ofir Lipman, Moshe Oron, KiloLambda Technologies, Ltd. (Israel)

Augmented reality (AR) is a live direct or indirect view of a physical, real-world environment whose elements augmented (or supplemented) by computer-generated sensory input such as sound, video, graphics or GPS data. As a result, the technology functions by enhancing one's current perception of reality. Artificial information about the environment and its objects can be overlaid on the real world, using a special optics and display. An example for such optic is a typical Head Mounted Display (HMD) which 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.

9470-41, Session 2

Ruggedized EUD case design

Dave Silvestris, DS Ultra Wireless LLC (United States)

Today our war fighters are using mobile computer communication devices on the battle field and the U.S. military have new requirements to protect their smart phones, tough pads and tablets. The DS Ultra Wireless - ruggedized End-User Device (EUD) case protects all mobile communication devices that include the benefits of improved human factors, and use the existing system cables with no EMI impacts to the existing system.

The effectiveness of the ruggedized (EUD) case comes from its layered design. Instead of a simple plastic or rubber case that clips around the smart phone or tough pad. The ruggedized EUD case unique features combine a polycarbonate "clamshell" skeleton with protective coating. The polycarbonate shell clips snugly around the EUD with internal fabricated edges to create a micro-USB "pocket" for consistent micro-USB cable stability and connection with the EUD. A rubber gasket channel and innovative locking feature allows for improved water seal. Surrounding the polycarbonate base shell is a PAXCON® force-resistant - Line-X TM protective coatings that smoothes over the base layer's hard edges and creates another level of shock protection for drop resistance, fire protection and durability. The layered design with PAXCON® - Line-X TM coating will allow the ruggedized EUD case to survive high G-Force impacts, water submersion, dirt, fire and high or low temperature extremes. The improved Human Factors include, a clamshell design that reduces the number of pieces to assemble. And the opposable "clip-notch" design for improved thumb-hold to open the clamshell and compression force to keep the case closed.

9470-8, Session 3

3D display considerations for rugged airborne environments

Tracy J. Barnidge, Joseph L. Tchon, Rockwell Collins, Inc. (United States)

The KC-46 is the next generation, multi-role, aerial refueling tanker aircraft being developed by Boeing for the United States Air Force.

Rockwell Collins has developed the Remote Vision System (RVS) that supports aerial refueling operations under a variety of conditions.

The system utilizes large-area, high resolution 3D displays linked with remote sensors to enhance the operators visual acuity for precise aerial refueling control. This paper reviews the design considerations, trade-offs and other factors related to the selection and ruggedization of the 3D display technology for this military application.

9470-9, Session 3

A guide for human factors research with stereoscopic 3D displays

John P. McIntire, Paul R. Havig II, Alan R. Pinkus, Air Force Research Lab. (United States)

In this work, we provide some common methods, techniques, information, concepts, and relevant citations for those conducting human factors-related research with stereoscopic 3D (S3D) displays. We give suggested methods for calculating binocular disparities, and show how to verify on-screen image separation measurements. We provide typical values for inter-pupillary distances that are useful in such calculations. We discuss the pros, cons, and suggested uses of some common stereovision clinical tests. We discuss the phenomena and prevalence rates of stereoanomalous, pseudo-stereoanomalous, stereo-deficient, and stereoblind viewers. The problems of eyestrain and fatigue-related effects from stereo viewing, and the possible causes, are enumerated. System and viewer crosstalk are defined and discussed, and the issue of stereo camera separation is explored. Typical binocular fusion limits are also provided for reference, and discussed in relation to zones of comfort. Finally, the concept of measuring disparity distributions is described. The implications of these issues for the human factors study of S3D displays are covered throughout.

9470-10, Session 4

Exploring immersive environments to aid urban intelligence, surveillance and reconnaissance operations

Jason Roll, Air Force Research Lab. (United States); Peter Venero, Infoscitex Corp. (United States); Donald Adkins, Air Force Research Lab. (United States); Sarah Lampke, Timothy MtCastle, Infoscitex Corp. (United States)

Intelligence, surveillance, and reconnaissance (ISR) operations in urban environments can be challenging due in part to the physical proximity and height of the buildings which can cause occlusions of sensors. A potential avenue to overcome the problems presented by the urban environment could be the exploitation of immersive environments. An immersive environment would increase an analyst's situation awareness to correctly select and position sensors for intelligence gathering. In completing a sensor management task, the operator must perform three basic actions: navigate through the environment, select sensors in the environment, and manipulate those selected sensors. The goal of this experiment was to investigate the impact that different fields of view (FOV) and different control devices had on those operator actions. While the FOV did not show a significant impact, significant differences were seen between the two control devices tested.

9470-11, Session 4

Augmented reality enabling intelligence exploitation at the edge

Sue E. Kase, Elizabeth K. Bowman, Heather E. Roy, Debra Patton, U.S. Army Research Lab. (United States)

Today's Warfighters need to make quick decisions while interacting in densely populated environments comprised of friendly, hostile, and neutral host nation locals. Enabled by ubiquitous mobile devices, social media has emerged as the local populace's dominant form of communications. The unprecedented speed social media enables many-to-many interactions coupled with the volatile nature of these environments, makes social media a critical intelligence source for the edge Soldier. However, there is a gap in the real-time processing of big data social media streams for edge intelligence. We introduce a big data processing pipeline that ingests, monitors, and performs a variety of analytics including noise reduction, pattern identification, and trend and event detection in the context of an area of operations (AOR). Results of the analytics are presented to the Soldier via an alerting framework and augmented reality (AR) device (Google Glass) when network connectivity to the pipeline is available, or pre-loaded to Glass prior to a mission using a powerful wearable computing device when pipeline connectivity is limited. Non-intrusive AR devices such as Glass can visually communicate contextually relevant alerts to the Soldier based on the current mission objectives, time, location, and observed or sensed activities. This real-time processing and AR presentation approach to knowledge discovery flattens the intelligence hierarchy enabling the edge Soldier to act as a vital and active participant in the analysis process. We report preliminary observations testing Glass in a person of interest detainment scenario simulating edge Soldier participation in the intelligence process in disconnected deployment conditions.

9470-12, Session 5

A virtual pixel software and hardware technology to increase projector resolution

Jeremy Straub, Benjamin M. Kading, Univ. of North Dakota (United States)

This paper proposes an approach to increasing projector resolution and minimizing projector size and weight. Increasing the resolution of the LCD (or similar) display used in projectors (in conjunction with increased light emissions, etc.) increases the resolution of the projected image and/or the distance that the projector can be from its screen. While increasing the size of the LCD panel represents one approach to producing increased resolution, this increases projector size and weight (particularly when the larger optics required to support this larger panel are considered). This paper proposes the incorporation of a mechanism to allow multiple pixels to be combined to create a higher resolution output image than the LCD (or similar) display used to create virtual pixels. This increases the effective resolution of the projector without necessitating a significant increase in the size of the LCD (or similar) display.

The proposed technology works by introducing a mechanism to combine the output of multiple LCD panels and the changing of the configuration of the pixels at a higher rate than the desired frame rate, to allow aggregation across time as well as spatial aggregation. This approach visually combines the coloration of adjacent pixels to create an approximation of what would be projected by a higher resolution screen. By increasing the frame rate, this creates the impression of a higher resolution image to the viewer.

The paper describes the approach in detail and the principles upon which it is based. Existing work demonstrating the proposed technique, using existing hardware, is presented. The potential for utilizing this technique beyond the proposed spatial-temporal aggregation approach that has been demonstrated is also discussed. The paper concludes by describing the prospective benefits provided by this technology.

9470-13, Session 5

A virtual pixel technology to enhance the resolution of monitors and for other purposes

Benjamin M. Kading, Jeremy Straub, Univ. of North Dakota (United States)

Current monitor and television displays utilize pixels to display a digitized approximation of the real world collected by a camera or generated computationally. The resolution of the camera (or generation technology) and the display determines how well this facsimile approximates reality. Technologies, such as the Retna display sold by Apple Computer, have produced a level of pixel density that exceeds the level of resolution perceptible by humans. These technologies, however, are still very expensive. This paper proposes a virtual pixel technology which utilizes a pixel combination function to average the output of multiple pixels to create a greater number of different virtual pixels, as compared to the number of emitting LCDs (or similar). This allows lower pixel density displays to produce the approximation of a higher pixel density display, while lowering overall production costs.

This technology works as follows. A computer or other device sends a signal to the display device to be projected that exceeds the hardware display fidelity. This signal is pre-processed by an in-monitor processing unit which is aware of the virtual pixel creation function and creates a series of pixel configurations to be displayed on the low resolution display to produce an approximation of the high-resolution image to the viewer.

This technology breaks the barrier between the pixels, allowing for more virtual pixels to be displayed than there are physical pixels. Each physical pixel's configuration is based on a weighted average of the virtual pixels that it contributes to.

This display technique, which is based on reversing the principles typically used in computer image super-resolution, utilizes a combination of software and hardware components. This paper provides an overview of the proposed technology, discusses its application to monitors and prospective extensions to other areas and concludes with a discussion of prospective next steps to its development.

9470-14, Session 6

Review of the evolution of display technologies for next generation aircraft *(Invited Paper)*

Joseph L. Tchon, Rockwell Collins, Inc. (United States)

Advancements in electronic display technologies have provided many benefits for military avionics. The modernization of legacy tanker transport aircraft along with the development of next-generation platforms, such as the KC-46 aerial refueling tanker, offers a timeline of the evolution of avionics display approaches. The adaptation of advanced flight displays from the Boeing 787 for the KC-46 flight deck also provides examples of

how avionics display solutions may be leveraged across commercial and military flight decks to realize greater situational awareness and improve overall mission effectiveness. This paper provides a review of the display technology advancements that have led to today's advanced avionics displays for the next generation, KC-46 tanker aircraft. In particular, progress in display operating modes, backlighting, packaging and ruggedization will be discussed along with display certification considerations across military and civilian platforms.

9470-15, Session 6

A neuroergonomic quasi-experiment: Predictors of situation awareness and display usability while performing complex tasks

Steven D. Harbour, U.S. Air Force (United States); James C. Christensen, Air Force Research Lab. (United States)

Situation awareness is the psychological ability to perceive information and act on it appropriately. This ability is central to human behavior, with both theoretical and practical implications. Existing theoretical models explain many aspects of situation awareness; however, the development of situation awareness out of basic perceptual abilities is largely unexplored. This quantitative research examined basic neurocognitive factors including visual abilities and working memory in order to identify their specific contributions to the formation of cognitive situation awareness, to in turn address this gap in situation awareness (SA) theory that must be linked before progress can be made. Aircraft piloting was used as a task where situation awareness is critical; trained USAF pilots represent a relatively homogenous, already expert population that reduced nuisance variance. This study assessed the predictive value of visual attentiveness (Va), perceptiveness (Vp), and spatial working memory (Vswm) as predictors of situation awareness in flight under varying task difficulty using repeated-measures comparisons. Repeated-measures ANOVAs, (Pearson) correlation and linear multiple regression modeling were used to assess the effects of the independent variables (three visual abilities) on the dependent variable SA and the interactions among the independent variables. The study participants were 19 C-27J pilots between the ages of 31 and 47, 1 female (6%) and 18 male (94%), selected from the Ohio Air National Guard. The IVA+ and N-back measure was administered to the participants prior to flight. In-flight situation awareness was both objectively and subjectively assessed for 24 flights. At the completion of this field experiment the data was analyzed and the tests were statistically significant for the three predictor visual abilities Vp, Va, and Vswm as task difficulty was varied, F(3,11) = 8.125, p = .008. In addition, multiple regression analyses revealed that the visual abilities together predicted a majority of the variance in situation awareness, R2 = 0.753, p = .008. Moreover, the Pearson correlation results indicated that Vp (r[12] = -0.816, p = .001) had the strongest relationship of the three neurocognitive factors for the overall flight. Post-Hoc hoc tests revealed a Cohen's f^(2)=3.05 yielding statistical power to be 0.98. This reveals that possessing the ability to have perceptivity, to be insightful, and to have discernment - to perceive that which is obscure, is most important. Interestingly during high task difficulty Va (r[12] = -0.583, p = .023) had the strongest correlation with SA, while during low task difficulty Vswm (r[12] = -0.634, p = .013) had the strongest correlation; this suggests that under high demand possessing the ability to concentrate and be devoted, to be detailed, and responsive becomes the largest determinant. While under low task demand responsiveness and insightfulness is less essential, the pilot seems to operate in an automatic manner only processing small bits of information using working memory that is responsible for the spatial orientation of one self and the environment. Allowing, Vswm to become the largest determinant of SA by simply being exposed. This work results in a significant addition and expansion to the existing theoretical model of situation awareness. There are practical implications as well, as this study highlights the potential for improved cockpit design and enhancing training by targeting attentional, perceptual, and visuospatial working memory skill learning.

9470-16, Session 6

A practical definition of eye-limited display system resolution

Charles J. Lloyd, Visual Performance, LLC (United States)

Please see attached document

The use of the term "eye limited resolution" (ELR) has increased over the past few decades, apparently due to the fact that modern display systems are capable of achieving resolutions that are nearer this limit than ever before. Examination of many papers that employ this term reveals several distinct definitions of ELR and a wide range of estimates of the pixel pitch required to achieve it. Many authors simply assert that ELR corresponds with 20/20 vision which is produced with a pixel pitch of 1 arcmin and provide no supporting discussion or citations. Others have explained that 1 arcmin is the stroke and gap width for the symbols on Snellen acuity charts for 20/20 vision and conclude that a pixel pitch of one arcmin is required. Spencer (2013) concluded that image artifacts can be visible for pixel pitches finer than 0.3 arcmin for images that have not been properly band-limited prior to spatial sampling. Hopper (2000) and his colleagues have asserted that the human visual system is many orders of magnitude more capable than current display technologies and conclude that a pixel pitch no larger than a few arcSEC will improve warfighter productivity.

Today the definitions and estimates of ELR vary wildly. Given that resolution is a primary driver of the performance, cost, and complexity of military imaging systems, a practical definition and a defensible estimate of ELR are needed.

9470-17, Session 6

Just noticeable color difference: implications for display systems

Daniel D. Desjardins, Northrup Grumman (United States)

According to MIL-HDBK-87213, the goal in full color displays is to have the color primaries widely separated (per CIE chromaticity coordinates) and/or provide filtering such that they will stay widely separated when exposed to, and mixed with, ambient light. Modern color displays boast of a phenomenal number of colors, typically based on the number of luminance (gray) levels per color sub-pixel raised to a power determined by the number of distinct color sub-pixels. But what do various studies tell us regarding an observer's ability to discriminate color differences and how this varies across the visual spectrum given the eye's non-linear efficiency relative to wavelength? Because display color should ("must" per the given handbook) be evaluated to assure that it is fully usable and aesthetically acceptable, this paper shall review existing studies regarding chrominance just noticeable differences to identify and characterize the number and spread of colors that are humanly perceivable.

9470-18, Session 7

Recent advances in OLED and flexible displays and their potential for application to aerospace and military display systems *(Invited Paper)*

Kalluri R. Sarma, Honeywell Technology (United States)

Organic light emitting diode (OLED) display technology has advanced significantly in recent years and it is increasingly being adapted in consumer electronics products with premium performance, such as smart phones, Tablet PCs and TVs. Even flexible OLED displays are being commercialized in consumer electronic devices such as smart phones. In addition to display media (I.e., OLED versus LCD), successful adoption of OLED displays for premium performance applications depends on the advances in a host of new enabling technologies including backplanes, pixel drive electronics,

pixel patterning technologies, encapsulation technologies and system level engineering. In this paper we will discuss the impact of the recent advances in LTPS and AOS TFTs, R, G, B and White OLED with color filter pixel architectures, encapsulation and system level engineering on the success of the OLEDs in consumer electronic devices. We will then discuss potential of these advances in addressing the requirements of OLED and flexible displays for the military and avionic applications.

9470-19, Session 7

Flexible displays for military applications

Jason T. Holmstedt, Physical Optics Corp. (United States)

Flexible displays have the potential for improved durability while accommodating new form-factors not achievable using traditional flat glass displays. This includes elimination of display fractures due to severe shock or impacts and the unique ability to conforming to arms or legs. As a result, flexible displays can be packaged with less mechanical protection than glass liquid crystal display (LCD) counterparts, especially when considering high pressure differential environments such as underwater applications. In this paper Physical Optics Corporation (POC) reviews the current state of commercial flexible display technologies including electrophoretic displays (EPDs) and organic light emitting diode (OLED) displays. We discuss the trade-offs of each in the context of wearable applications while addressing the broader military need for flexible display technology. We present POC's flexible display system architecture including stand-alone battery powered processing electronics, customized Android operating system, and demonstration packaging. Finally, we review the results of testing and evaluation of POC's flexible displays systems including use under various lighting conditions and with a variety of screen content ranging from mapping to tactical video feeds. We conclude with recommendations for future display system enhancements and a roadmap for transitioning the technology for tactical applications.

9470-20, Session 8

Analog video to ARINC 818

Paul Grunwald, Great River Technology, Inc. (United States)

Many aircraft, both commercial and military, are still using analog video such as RS-170, RS-343, or STANEG 3350. Though the individual digital components many be inexpensive, the cost to certify and retrofit an entire older aircraft fleet may be prohibitively expensive. A partial or incremental upgrade program where analog cameras remain in use but the data is converted and processed digitally is a proven option. This paper will describe Great River Technology's experience in converting multiple channels of RS-170 and multiplexing them through a concentrator to put them on a single fiber. The paper will also discuss alternative architectures and how ARINC 818 can be utilized with legacy systems.

9470-21, Session 8

Electro-textile garments for power and data distribution

Jeremiah Slade, Infoscitex Corp. (United States);
Carole Winterhalter, U.S. Army Natick Soldier Research, Development and Engineering Ctr. (United States)

Historically, wearable electronic networks have been formed using either wireless modules or cables. One of the principal drawbacks of purely wireless networks is that they are typically not able to efficiently, securely or discreetly transmit power and are therefore reliant on batteries to power each device. Cables address this problem by enabling discreet point-to-point transmission of both power and data. However, most of these options are relatively bulky and can be difficult to integrate into textile products without discomforting the wearer or creating snag hazards. They also provide limited design flexibility in terms of where, and in which types of garments, they can be placed since they typically require that the integrator route them through available channels in the garment such as inside seams or between layers of fabric. The fundamental problem with these cabling approaches is that even the most flexible and ergonomic transmission media are inherently different from the fabric used to construct the garment and must be applied either during or after garment assembly. Incorporation of the networks at these late stages of garment fabrication has been repeatedly shown to produce a number of performance, comfort, and wearability problems.

The solution to these issues is to integrate the transmission media at the fabric's yarn level using conventional textile production processes and equipment. While the integration of electrically conductive media into conventional broadloom fabrics is not entirely new, much of the work done to-date has utilized materials that are so dissimilar from conventional yarns that they significantly degrade the comfort and performance of the finished product. Even more problematic is the fact that these conductive pathways are lost when pattern pieces are cut and sewn together to form a garment.

IST has addressed these issues by developing and reducing to practice the critical technologies needed to integrate large-scale cross-seam electrical functionality into a variety of textile systems. These technologies form the basis of IST's SEWit (Selectively Enabled Wiring in Textiles) toolkit. The product of over eight years of development, this toolkit is highly adaptable and can be used with any woven fabric. All aspects of this toolkit, from the computer-aided design tools, to the conductive yarns, to the weaving process, and the assembly and activation of the final product, involve little or no alteration to established textile production methods. In many ways the development of this toolkit has paralleled that of the modern circuit board, and like the circuit board it will greatly streamline the development time and cost of all subsequent products. Using IST's SEWit technology unobtrusive electrical networks can be created in a variety of textile products including garments, plate carriers, backpacks and tents, without the need for conventional wires or cables. This change will eliminate the shortcomings associated with previous e-textile and wearable-electronic products and reduce overall system bulk and weight. Using this technology IST is able to develop textile products that do not simply support or accommodate a network but are the network.

9470-23, Session 8

Interoperabilty, speaking the same language via tactical data link systems

Erdem Hekimhan, Savas Ozkaynak, Turkish Air War College (Turkey)

Today, well improved technology and the knowledge ingredients of this technology has just given the name of this era. In the near future technological researches and developments will form the bases of military and civil technological developments. The foundations of civil and military technological developments depends on the information in shaping precision, speed and accuracy, high reliability, real-time information transmission speed and to maintain the information securely. In addition to land, sea and air platforms there will be space and cyber platforms when the operational environment of there future is imagined. These spaces will change the aim of the war and military operation areas will become a dynamic battlefield. To keep up with this pace, establishing common operational picture through interoperability and the real-time/near-real time transmission of this picture will change the course of operation. In order to increase situational awareness of performing operation platforms required to owned national use of information technology. The objective of Tactical Data Link (TDL) Systems are real-time or near real-time data transmission between friendlies, allies and the combined forces by C4ISR platforms and the systems. This paper was written with in the framework of information and data sharing needs. Tactical Data Link Systems which was developed in the early 1950s will be considered by technological developments, use in operations, joint force dynamics improvements. In this context, Tactical Data Link Systems, will be examined under the joint operations and central

command via interoperability. Tactical Data Link Systems, which is a part of Network-Centric Warfare, are considered to be successful to today's and tomorrow's modern operations.

9470-24, Session 8

Can unmanned aerial vehicles radically change the border security?

Abdullah Erkan, Turkish Air Force (Turkey)

In this study the utulization of UAV's in border security is analysed and the capabilities of available UAV's are examined from a warfighter point of view. It is concluded that, governments will revise their border security policies to challenge drug dealers, arms and human trafficking, terrorist activities and illegal immigration and the combat proven UAV's will increasingly be used in border security.

9470-37, Session 8

Augmented reality: the applications of augmented reality in military area and military schools

Isa Haskologlu, Kara Harp Okulu (Turkey); Mehmet Sisman, Enes Erol, Turkish Military Academy (Turkey)

Recently, as a new technology, Augmented Reality is used in several aspects of life, such as architecture, education, publishing, military, shopping, medicine, social life, etc. In this paper, Augmented Reality and its application fields are summarized, some new aspects are offered in using Augmented Reality in military schools since the education of a soldier is of great importance.

9470-38, Session 8

Performance and lifetime enhancements to legacy analog head up displays systems, in military applications, through affordable digital upgrades

William P. Bleha Jr., HOLOEYE Systems Inc. (United States); Paul L. Wisely, HOLOEYE Systems Inc. (United Kingdom)

Large numbers of military aircraft that were designed and manufactured in the last century remain in service today; world economics indicate that they are unlikely to be replaced in the foreseeable future. As their avionic systems age, in service support becomes increasingly expensive, hence ways need to be identified to control and reduce these costs.

This paper describes an affordable approach to reducing the costs associated with head up display pi-lots' display units, through novel design concepts; these concepts replace the cathode ray tubes and their associated electronics with an all-digital system that seamlessly interfaces, both optically and electronically, with the legacy components of the HUD display unit.

Though such schemes have been explored by several manufacturers in the past, they have struggled to achieve an ideal solution that would enable the HUDs to fully meet their original system design specifi-cations; the challenges involved in achieving this goal are further discussed in this paper, and ap-proaches to realize the ideal solution described.

9470-39, Session 8

LCOS-based digital rifle scope display

William P. Bleha Jr., HOLOEYE Systems Inc. (United States); Paul L. Wisely, HOLOEYE Systems Inc. (United Kingdom)

A rifle scope with a compact digital integrated display based on high resolution reflective LCOS technology has been developed, allowing information overlay in the direct view optic field. The HOLOEYE 0.37" diagonal, HED 7200 microdisplay image source with a resolution of 1280 x 720 pixels has been incorporated into a high performance Night Force Optics rifle scope. The system displays monochrome, hyper red, text and symbology to provide the user clear, high contrast imagery from bright daytime to dark nighttime conditions. The advantages of LCOS for this application are: high contrast ratio (>500:1) so that there is no imaged red box; high illumination efficiency due to the 60+% reflectivity of the LCOS panel; and high brightness up to 8000 ftL for use in high ambient light environments.

9470-40, Session 8

The development of a new custom 3 ATI display

Adrian Miscovich, Haim Waksman, Adi Holzman, Astronautics CA (Israel)

This paper presents the development, the challenges, the achievements and the performance of a custom 3ATI Display Head Assembly (DHA) to be used in avionic applications. The DHA includes a new custom LCD developed specifically for this application, a new high performance backlight (NVIS compatible) and the mechanical packaging of the DHA. Technological achievements are highlighted such as optical design to achieve low sunlight reflections, saturated colors even with NVIS compatibility and the design to meet severe environmental conditions. The paper describes additional important achievements such as low cost and very fast development time. This development opens the door to the fast development of low cost DHAs having any size and which meet avionic requirements.

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9470-36, Session PSTue

Development of a helmet/helmet-display-unit alignment tool (HAT) for the Apache helmet and display unit

William E. McLean, Jonathan K. Statz, Victor A Estes, Shawn M Booms, John S Martin, Thomas H. Harding, Clarence E. Rash, U.S. Army Aeromedical Research Lab. (United States)

Program Manager (PM) Apache Block III, contacted the U.S. Army Aeromedical Research Laboratory (USAARL) requesting assistance to evaluate and find solutions to a government developed Helmet Display Unit (HDU) device, called the Mock HDU for helmet alignment of the Apache Advanced Integrated Helmet (AAIH). The AAIH is a modified HGU-56/P to replace the current Integrated Helmet and Sighting System (IHADSS). The current flashlight based HDU simulator for helmet/HDU alignment was no longer in production or available. Proper helmet/HDU alignment is critical to position the right eye in the small HDU eye box to obtain image alignment and full field of view (FOV). The initial approach of the PM to developing a helmet/HDU fitting device (Mock HDU) was to duplicate the optical characteristics of the current tactical HDU using less complex optics. However, the results produced questionable alignment, FOV and distortion issues, with cost and development time overruns. After evaluating the Mock HDU, the USAARL proposed a cost effective, less complex optical design called the Helmet/HDU Alignment Tool (HAT). This poster will show the development, components, and evaluations of the HAT compared to the current flashlight HDU simulator device. The laboratory evaluations included FOV measurements and alignment accuracies compared to tactical HDUs. The Apache helmet fitter technicians and Apache pilots compared the HAT to the current flashlight based HDU and ranked the HAT superior.

9470-25, Session 9

A history of helmet mounted displays *(Invited Paper)*

Bobby D. Foote, Rockwell Collins, Inc. (United States); James E. Melzer, Rockwell Collins Optronics (United States)

Helmet Mounted Displays (HMD) were introduced as simple sight in the Mirage F1AZ by the South African Air Force to aid in the targeting of heat seeking missiles in the 1970s. In more than 40 years of development the HMD has become an integral part of the pilot and soldier arsenal, proving to be a key force multiplier and reducing user workload. Rockwell Collins has been a key player in the development of modern Helmet Mounted Display technology and currently is fielding 4 major HMDs supporting pilots around the world. This paper will outline the history of HMDs over the last 40 years for fixed wing, rotorcraft and soldiers. We will walk through the developments, and testing required for introduction of HMDs into the modern pilot environment. Within the paper we will point out some of the misconceptions, facts and legends of HMDS. We will include impacts of commercial devices on the current military market. The paper will conclude with our vision of a potential future for HMDs in the next 40 years.

9470-26, Session 9

The impact of human factors, crashworthiness and optical performance design requirements on helmet-mounted display development from the 1970s to the present *(Invited Paper)*

Thomas H. Harding, Clarence E. Rash, William E. McLean, John S. Martin, U.S. Army Aeromedical Research Lab. (United States)

Driven by the operational needs of modern warfare, the helmet-mounted display (HMD) has matured from a revolutionary, but impractical, World War I era idea for an infantry marksman's helmet-mounted weapon delivery system to a sophisticated and ubiquitous display and targeting system that dominates current night warfighting operations. One of the most demanding applications for HMD designs has been in Army rotary-wing aviation, where HMDs offer greater direct access to visual information and increased situational awareness in an operational environment where information availability is critical on a second-to-second basis. However, over the past 40 years of extensive HMD development, a myriad of human factors, crashworthiness, ergonomic, and image quality issues have both frustrated and challenged designers. While it may be difficult to attain a full consensus on which are the most important HMD design factors, certainly head-supported weight, exit pupil size, field-of-view, image resolution and physical eye relief have been among the most critical. A confounding factor has been the interrelationship between the many design factors, such as early attempts to use non-glass optical elements to lower head-supported weight, but at the cost of image quality. This paper traces how the role of the demanding performance requirements placed on HMDs by the Army aviation community has impacted the progress of HMD designs towards the Holy Grail of HMD design: a wide field-of-view, high resolution, binocular, full color, totally crashworthy system.

9470-27, Session 9

In the blink of an eye: head mounted displays development within BAE Systems *(Invited Paper)*

Alexander A. Cameron, BAE Systems (United Kingdom)

There has been an explosion of interest in head worn displays in recent years, particular for consumer applications with an attendant ramping up of investment into key enabling technologies to provide what is essence a mobile computer display. However, head mounted system have been around for over 40 years and today's consumer products are building on a legacy of knowledge and technology created by companies such as BAE Systems who have been designing and fielding helmet mounted displays (HMD) for a wide range of specialist applications. Although the dominant application area has been military aviation, solutions have been fielded for solider, ground vehicle, simulation, medical, racing car and even subsea navigation applications.

What sets these HMDs apart is that they provide the user with accurate conformal information embedded in the users real world view where the information presented is intuitive and easy to use because it overlays the real world and enables them to stay head up, eyes out, - improving their effectiveness, reducing workload and improving safety.

Such systems are an enabling technology in the provision of enhanced Situation Awareness (SA) and reducing user workload in high intensity situations. Safety Is Key; so the addition of these HMD functions cannot detract from the protection functions of helmets which may also include life support and audio communications. Their development embraces a wide range of technologies and design know how so the developed of successful HMDs embrace an exotic mix of technologies and capabilities ranging from optical system and display technology, image processing, helmet tracking, human factors, physical protection, information management, audio communications, night vision sensors and many others.

These capabilities are finding much wider application in new types of compact man mounted audio/visual products enabled by the emergence of new families of micro displays, novel optical concepts and ultra-compact low power processing solutions. This paper therefore provides a summary of BAE Systems journey in developing and fielding Head Mounted systems, their applications and the key enabling technologies. It also attempts to look forward to provide a vision on the future for head worn system their capabilities and applications.

9470-28, Session 9

A review of head-worn display research at NASA Langley Research Center *(Invited Paper)*

Jarvis J. Arthur III, Randall E. Bailey, Steven P. Williams, Lawrence J. Prinzel III, Kevin J. Shelton, NASA Langley Research Ctr. (United States); Denise R Jones, NASA Langley Research Ctr (United States); Vincent E. Houston, NASA Langley Research Ctr. (United States)

NASA Langley has conducted research in the area of helmet-mounted/head-worn displays over the past 20 years. Though military aviators have extensive experience in helmet-mounted displays, a helmet is untenable for commercial operations. Initially, NASA Langley's research focused on military applications, but recently has conducted a line of research in the area of head-worn displays for commercial and business aircraft. This work has revolved around several simulation experiments as well as flight tests to develop technology and data for industry and regulatory guidance. The research lends credence that a small, sunglasses-type form factor of the head-worn display would be acceptable to commercial pilots. The research further suggests that a small, light head-worn display may serve as an "equivalent" head-up display (HUD) with safety, operational, and cost benefits. The present paper shall summarize the results of NASA's helmet-mounted/head-worn display research and discuss future research directions. Of note, the work will track progress in wearable collimated optics, with improved head tracking, reduced latency, and lighter weight, whereby, a sunglasses form-factor is becoming technologically feasible.

9470-29, Session 10

Flight test of a head-worn display as an equivalent-HUD for terminal operations

Kevin J. Shelton, Jarvis J. Arthur III, Lawrence J. Prinzel III, Stephanie N. Nicholas, Steven P. Williams, Randall E. Bailey, NASA Langley Research Ctr. (United States)

Research, development, test, and evaluation of flight deck interface technologies is being conducted by NASA to proactively identify, develop, and mature tools, methods, and technologies for improving overall aircraft safety of new and legacy vehicles operating in Next Generation Air Transportation System (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 CFR 91.175 describes a possible operational credit which can be obtained with airplane equipage of a HUD or an "equivalent"' display combined with Enhanced Vision (EV). If successful, a HWD may provide the same safety and operational benefits as current HUD-equipped aircraft but for significantly more aircraft in which HUD installation is neither practical nor possible. A flight test was conducted to evaluate if the HWD, coupled with a head-tracker, can provide an equivalent display to a HUD. Approach and taxi testing was performed on board NASA's experimental King Air aircraft in simulated IMC conditions. Analysis of HWD performance and pilot comments will be discussed.

9470-30, Session 10

Dynamic registration of an optical see-through HMD into a wide field-of-view rotorcraft flight simulation environment

Franz Viertler, Manfred Hajek, Technische Univ. München (Germany)

To overcome the challenge of helicopter flight in degraded visual environment current research considers head-mounted displays with 3D-conformal (scene-linked) visual cues as most promising display technology. For pilot-in-the-loop simulations with HMDs a highly accurate registration of the augmented visual system is required. In rotorcraft flight simulators the outside visual cues are usually provided by a dome projection system, since a wide field-of-view (e.g. horizontally > 200° and vertically > 80°) is required, which can rarely be achieved with collimated viewing systems. But optical see-through HMDs mostly do not have an equivalent focus compared to the distance of the pilot's eye-point position to the curved screen, which is also dependant on head motion. Hence a dynamic vergence correction has been implemented to avoid binocular disparity. In addition, the parallax error induced by even small translational head motions is corrected with a head-tracking system to be adjusted onto the projected screen. For this purpose two options are presented. The correction can be achieved by rendering the view with yaw and pitch offset angles dependant on the deviating head position from the design eye-point of the spherical projection system. Furthermore it can be solved by implementing a dynamic eye-point in the multi-channel projection system for the outside visual cues. Both options have been investigated for the integration of a binocular HMD into the Rotorcraft Simulation Environment (ROSIE) at the Technische Universitaet Muenchen. Pros and cons of both possibilities with regard to integration issues and usability in flight simulations will be discussed.

9470-31, Session 10

Visibility of monocular symbology in transparent head-mounted display applications

Marc Winterbottom, USAF School of Aerospace Medicine (United States); Robert Patterson, 711 HPW/RHX (United States); Byron Pierce, Certified Human Factors Professional (United States); James Gaska, Steven Hadley, USAF School of Aerospace Medicine (United States)

With increased reliance on head-mounted displays (HMDs), such as with the JHMCS and F-35 HMDS, research concerning factors affecting visual performance has also increased in importance. Although monocular HMDs have been used successfully for many years, a number of authors have reported significant problems with their use. Certain problems have been attributed to binocular rivalry when differing imagery is presented to the two eyes.

With binocular rivalry, the visibility of the images in the two eyes fluctuates, with one eye's view becoming dominant, and thus visible, while the other eye's view is suppressed, which alternates over time. Rivalry is almost certainly created when viewing an occluding monocular HMD with one eye while the other eye views a real-world scene. For semi-transparent

monocular HMDs, however, much of the scene is binocularly fused, with additional imagery superimposed in one eye. Binocular fusion is generally thought to prevent rivalry.

The present study was designed to investigate differences in visibility between monocularly- and binocularly-presented symbology at varying levels of contrast, and while viewing simulated flight over terrain at various speeds. Visibility was estimated by measuring the time required to identify a test probe (tumbling E) embedded within other static symbology. Results indicated that there were large individual differences, but that visibility of the target decreased with increased speed or decreased contrast under monocular viewing relative to binocular viewing conditions. These results provide a starting-point for further research at USAFSAM concerning visual performance with the use of HMDs such as the JHMCS and F-35 HMDS.

9470-32, Session 10

Visual fatigue induced by optical misalignment in binocular devices: application to night vision binocular devices

Maria Gavrilescu, Defence Science and Technology Organisation (Australia); Josephine Battista, Michael R. Ibbotson, National Vision Research Institute (Australia); Peter Gibbs, Defence Science and Technology Organisation (Australia)

The additional and perhaps unnatural eye-movements required to fuse binocular images that are misaligned can lead to visual fatigue and decreased task performance. The eyes have some tolerance to optical misalignment. However, a survey of scientific literature reveals a wide range of recommended tolerances but offers little supporting experimental evidence. Most experimental studies are based on small numbers of participants exposed to brief periods of optical misalignment. Therefore these published tolerance limits might have limited relevance for long-duration exposure to misaligned binocular devices.

Prolonged use of binocular devices may cause visual fatigue irrespective of binocular alignment. This study attempts to identify measures most sensitive to misalignment in order to establish relevant tolerance limits.

Firstly, we developed a rugged and deployable test bench that can measure binocular alignment with a reproducibility error of less than one arcminute. The bench was used to identify and investigate major factors affecting the stability of the optical misalignment over time. Our results indicated that the optical misalignment of a given device changed over time as a function of the operational usage and thermal history of the device.

Secondly, participants were exposed to experimentally controlled levels of optical misalignment typical of those measured on in-service binocular night vision devices. The visual fatigue of each participant was assessed via a set of oculomotor parameters. The oculomotor parameters showing high sensitivity to optical misalignment were compared for subjects exposed to extended periods of misalignment in a baseline reading task and a task using an actual night vision device.

9470-33, Session 11

Enhancing head and helmet-mounted displays using a virtual pixel technology

Benjamin M. Kading, Jeremy Straub, Univ. of North Dakota (United States)

Head and helmet-mounted displays utilize pixels to display a digitized approximation of the real world. The resolution of the source imagery and the head / helmet-mounted display determines how well the image approximates reality. Head and helmet-mounted displays must have a higher pixel density (as compared to a monitor or projected image) to create the same level of perceived resolution. This paper proposes a virtual pixel technology which incorporates a mechanism to allow multiple adjacent pixels to be aggregated both spatially and temporally to create a higher resolution output from the head/helmet-mount display. This allows current display pixel density levels to produce a higher effective resulting resolution.

This technology begins with a video source sending a signal to the head / helmet-mounted display device that exceeds the hardware display fidelity. The signal is pre-processed by an internal processing unit which is aware of the virtual pixel creation function. This pre-processor creates a series of pixel configurations to be displayed at a refresh rate higher than the target frame rate. Each physical pixel's configuration is determined from the weighted average of the virtual pixels that it contributes to.

This technique requires a hardware-software system, which is presented in this paper. It begins by providing an overview of the proposed technology. It then discusses its application of the base technology to head and helmet-mounted displays. Finally, it concludes with a discussion of how to advance the technology's development.

9470-34, Session 11

Polymer prisms for head hounted optical systems

Dave Schmidt, Howard Wong, Robert Benson, Rochester Precision Optics, LLC (United States)

Prisms are commonly used in in head mounted displays as image combiners and mirrors. Reduction of weight is of paramount importance in these devices. Polymer materials are ideal for the reduction of weight. In addition, the complexity in the optical and mechanical design of these systems can be reduced via the use of curved, even free form aspheric, optical surfaces and integral mounting features that are part of the prism. While polymer materials reduce weight, reduce complexity and may be produced at very low cost when the production volume is large, they do not have the internal optical quality of glass. Also the quality of the optical surfaces may suffer in comparison with conventionally polished glass optics. In this paper the relative merits of the available materials, optical design opportunities, mechanical mounting concepts and manufacturing approaches are discussed. For the material properties, the refractive index homogeneity and environmental durability of the various polymers are discussed in relation to the selection of an appropriate polymer for the particular application. The notion of a balance of properties in polymer selection will be presented. For manufacturing the relative advantages and disadvantages of single point diamond turning and injection molding are discussed. Some results from actual prisms will be given.

9470-35, Session 12

The impact of coloured symbology on cockpit eyes-out display effectiveness: a survey of key parameters

Maha Fares, Derek R. Jordan, BAE Systems (United Kingdom)

Colour is becoming a baseline requirement in the avionic displays market. Implemented for decades in Head Down Displays (HDD), it is thought to enhance Situational Awareness and minimise errors in decision making. Even though a wide colour gamut can be achieved in eyes-out display devices, its application and its usefulness for symbology effectiveness remains debatable. Reconciling these two issues would significantly improve the standardisation of eyes-out displays, enhancing safety while reducing costs of ownership.

However, designing a robust set of colour symbology, for all eyes-out display types and in all conditions of operation - in particular Degraded Visual Environments (DVE) - is less straightforward than in HDD. In fact, the transparency dimension of the display can cause a divergence between the intent of the coloured symbology and its recognition/discrimination by the user.

The effectiveness of colour as an attention getter and the associated design constraints for real situations are investigated. This report summarises the main features to take into account when assigning colour to an eyes-out display, including a discussion on the Green/Amber/Red code. The approach suggested aims at developing a model that uses colour symbology effectively in both the aircraft space- and time- frames simultaneously.

In colour eyes-out displays, mission performance is clearly dependent on:

- Display transparency

- Information categorisation

- Colour perception by the pilot

The interaction between these elements is key to designing a coherent set of colour design rules and the paper ends with a set of recommendations for good practice in eyes-out symbology design.

Conference 9471: Degraded Visual Environments: Enhanced, Synthetic, and External Vision Solutions 2015

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9471-1, Session 1

Subjective evaluation of a prototype night vision goggle

Gregory J. Hardy, The Boeing Co. (United States); Bobby D. Foote, Rockwell Collins, Inc. (United States)

ABSTRACT: Digital Night Vision sensor technology has the potential to provide significant new night vision capabilities for military aviators. Before new capabilities can fielded, however, the combined sensor-processor-display chain must achieve a level of night vision performance on-par with current-generation photo-multiplier tube (PMT) -based night vision goggles across the entire range of lighting conditions. This paper provides an overview of Rockwell Collins's ISIE-11 based Digital Night Vision Goggle (DNVG) intended to eventually replace traditional PMT goggles in a variety of military aviation and infantry applications. It also reports on an initial series of evaluations performed by Boeing aircrew in laboratory and flight environments. Laboratory lighting levels ranged from "overcast starlight" to "full moon", and airborne evaluations in a light aircraft were conducted under "starlight" and "half-moon" conditions at a realistic tactical altitude. Each evaluation provided a direct, subjective comparison between a modern PMT NVG and the DNVG prototype. The paper concludes with a general discussion of future capabilities that are enabled on a DNVG platform.

9471-3, Session 1

Passive real-time millimeter wave imaging for degraded visual environment mitigation

Thomas E. Dillon, Christopher A. Schuetz, Richard D. Martin, Daniel G. Mackrides, Charles Harrity, Phase Sensitive Innovations, Inc. (United States); Dennis W. Prather, Univ. of Delaware (United States)

Degraded visual environments create life-threatening situations for aircraft pilots due to loss of ground reference, which can result in accidents during navigation or landing. Imaging in millimeter wave spectral bands presents the opportunity to maintain pilot's situational awareness despite DVE. Millimeter waves suffer low atmospheric attenuation as well as minimal scattering loss due to airborne particulates, e.g. blowing sand, dust, fog, and other visual obscurants. As such, Phase Sensitive Innovations has developed a passive, real-time mmW imager to address brown-out situations for rotorcraft. Our imager is based on a distributed aperture array with conversion of detected RF signals to optical frequencies for processing and image formation. Recently we performed operationally representative field testing of our sensor while imaging various natural and man-made objects. We will present the results of these tests as they demonstrate the phenomenology encountered in this spectrum as well as the capabilities of our imaging technology.

9471-4, Session 1

Testing of an improved passive millimeter wave imager for degraded visual environments applications

Colin D. Cameron, Rupert N. Anderton, QinetiQ Ltd. (United Kingdom); John N. Sanders-Reed, The Boeing Co. (United States); Dennis J. Yelton, Boeing-SVS, Inc. (United States); Gordon N. Sinclair, James G. Burnett, Philip J. Kent, QinetiQ Ltd. (United Kingdom); Jeff J. Güell, The Boeing Co. (United States)

This paper discusses the optical testing and imaging performance of the improved passive mm-wave imager design for use in degraded visual environments for base security and helicopter navigation reported in the 2014 conference.

The testing regime starts with optical component testing, to show whether each optical component conforms to its specification, and predict what effect each component will have on system performance. The testing described includes metrology of surface profiles, measurements of loss for each component, measurements of point spread functions and encircled energy of each component with optical power, and measurements of polarising efficiency on the polarising material and quarter–wave plate used in the system. The performance of the receivers is also measured in terms of noise equivalent temperature difference, frequency response and receiver feed horn beam pattern. Also described is the design of two corrector test lenses which allow either imager component with optical power to form a sharp image without the presence of the other component, and thus be tested individually.

Testing of the full optics is described, both using a single scanned receiver and later the full receiver array. The former gives better sampled point spread functions; the latter better represents the full system. The loss, effective aperture, field of view, depth of field, narcissus, thermal and fixed-pattern noise are also measured. Iterative methods to set the tolerance compensation and optimise the scan conversion look up tables are described.

Finally testing of the system imaging performance on bar targets and simple scenes is described.

9471-5, Session 1

LandSafe precision flight instrumentation system for rotorcraft operations in degraded environments

Pri Mamidipudi, Elizabeth Dakin, Optical Air Data Systems, LLC (United States)

Helicopter hover, landing, and take-off operations in darkness, dust, fog, rain, snow, and high winds is an integral part of military and commercial flight operations. OADS has developed and flight-tested a standalone LDV-based optical sensor suite capable of precisely measuring and reporting height above ground, groundspeed, ground drift, and air data at an FCS capable data rate from a helicopter platform under all environmental conditions. Details about the sensor and recent flight test results from multiple platforms will be presented.

9471-7, Session 2

Three-dimensional landing zone joint capability technology demonstration results

James C. Savage, Air Force Research Lab. (United States)

The Three-Dimensional Landing Zone (3D-LZ) Joint Capability Technology Demonstration (JCTD) was a United States Central Command sponsored

27-month technology development program to develop 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 built 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 provides 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 the significant ladar technology development milestones leading to the JCTD, describes the LADAR and associated technologies within 3D-LZ, and summarizes the results of the flight testing conducted at Yuma Proving Ground in 2014.

9471-8, Session 2

An investigation in processing techniques for sidelobe suppression in millimeter wave DVE radars for imagery

Janeen Winne, U.S. Army Communications-Electronics Research Development and Engineering Command (United States); Antoinette Beasley, Lee Moyer, EOIR Technologies (United States)

Degraded visual environment (DVE) conditions, such as dust, snow, and smog, increase the susceptibility of rotary winged aircraft to crashes due to the pilot's inability to properly detect objects, other aircraft, cables, and terrain that pose a threat when flying or landing. As such, DVE and applicable solutions have been a focus of various military programs in the Army. These solutions often include multifunction sensor technology, the fusing of sensor and terrain database data, navigation solutions, and 2D and 3D synthetic visualization. The use of mmW radar has been shown to be a valuable part of the sensor solution in a DVE environment, as it enhances pilot situational awareness in all DVE conditions and provides additional functionality such as the detection of moving targets at significant standoff ranges. However, real beam imaging using mmW radar sensors often results in an image that is not intuitive for pilotage. This paper focuses on the use of a W-band mmW radar sensor, which is known to suffer from high azimuth and elevation sidelobes operating in DVE mode in an operationally relevant environment, and investigates data post-processing techniques that can be applied to collected sensor data for improved sensor performance. The investigation will apply a simplified, one-dimensional version of the CLEAN algorithm to the data in azimuth and in elevation to study the improvement offered when utilizing sidelobe suppression techniques with the goal of improving radar imaging for pilotage.

9471-9, Session 2

Flight test results of ladar brownout look-through capability

Stephen Stelmash, Fairchild Controls Corp. (United States); Thomas R. Muensterer, Patrick Kramper, Christian Samuelis, Daniel Buehler, Matthias Wegner, Airbus Defence and Space (Germany); Sagar Sheth, Ferchau Engineering (Germany)

The paper discusses recent results of flight tests performed with the Airbus Defence and Space ladar system at Yuma Proving Grounds. The ladar under test was the SferiSense® system which is in operational use as an in-flight obstacle warning and avoidance system on the NH90 transport helicopter. Just minor modifications were done on the sensor firmware to optimize its performance in brownout. Also a new filtering algorithm fitted to segment dust artefacts out of the collected 3D data in real-time was employed. The results proved that this ladar sensor is capable to detect obstacles through brownout dust clouds with a depth extending up to 300 meters from the landing helicopter.

9471-10, Session 2

DVE flight test results of a sensor enhanced 3D conformal pilot support system

Thomas R Muensterer, Philipp Voelschow, Bernhard Singer, Michael Strobel, Patrick Kramper, Airbus Defence and Space (Germany)

The paper presents results and findings of flight tests of the Airbus Defence and Space DVE system SFERION performed at Yuma Proving Grounds. During the flight tests ladar information was fused with a priori DB knowledge in realtime and 3D conformal symbology was generated for display on an HMD. The test flights included low level flights as well as numerous brownout landings.

9471-11, Session 3

Fusion of synthetic and live imagery in a two view domain

Larry Schaffer, GE Intelligent Platforms (United States)

The paper examines the considerations required when merging video of different formats, resolutions, FoVs and PoVs, particularly when Steered sensors are employed with HMDs. Adaptive Fusion methodology is discussed and representations of resulting visualizations are presented.

9471-12, Session 3

Data Fusion for a DVE Solution

Noah Baird, Michael Crisafulli, ENSCO Avionics, Inc. (United States)

An effective Degraded Visual Environment (DVE) solution integrates and displays data from a number of complimentary sources. The visualization backbone is a Synthetic Vision System (SVS) using an up-to-date synthetic terrain database with high resolution elevation data for the immediate DVE area, enhanced by recent high-resolution photo imagery of the area draped over the 3D terrain. Effectiveness is further enhanced by displaying 3D structure and vegetation models derived from on-board sources such as cultural features and obstacle databases, or in real-time from off-board sources such as data linked traffic and reconnaissance or forward-observer reports. The full solution incorporates real-time sensor data processed to identify vertical obstacles (such as towers), horizontal obstacles (wires), and three-dimensional obstacles (buildings), positioned on the synthetic terrain in their detected positions. The sensors may be on board the aircraft, but such interpreted data may also be relayed from a remote source that is viewing the DVE area. Actual sensor imagery can be merged with the synthetic view so that the sensor imagery and underlying SVS terrain are viewed together. Lastly, how the fused data is presented affects the aircrew's ability to intuitively grasp the situation in the DVE area. An external wingman view shows the situation all around the aircraft rather than just in front. When the SVS is integrated with a helmet-mounted display system, it is possible to provide virtual "x-ray" vision by providing the fused synthetic view even when the actual view is obscured by the airframe.

9471-13, Session 3

Is OpenSceneGraph an option for ESVS displays?

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

Modern Enhanced and Synthetic Vision Systems (ESVS) usually incorporate complex 3D displays, for example, terrain visualizations with color-coded altitude, obstacle representations that change their level of detail based on distance, semi-transparent overlyays, dynamic labels, etc. All of these elements can be conviniently implemented by using a modern scene graph implementation. OpenSceneGraph (OSG) offers such a data structure. Furthermore, OSG includes a broad support for industry-standard file formats, so that 3D data and models from other applications can be used. OSG has a large user community and is driven by open source development thus a selection of visualization techniques is available and often solutions for common problems can be found easily in the communities discussion groups. On the other side, documentation is sometimes out-dated or non-existing. We investigate which ESVS applications can be realized using OSG and on which platforms this is possible. Furthermore, we take a look at technical and legal limitations.

9471-14, Session 3

Combining IR imagery and 3D lidar-based symbology for a helicopter DVE support

Thomas R. Muensterer, Martin J. Kress, Airbus Defence and Space (Germany); Mark C. Lupton, Graham Passey, SELEX ES (United Kingdom); Dennis Fadljevic, Airbus Defence and Space (Germany); Tony Lamb, SELEX ES (United Kingdom)

This paper describes the results of an HMI development and ground tests related to the combination of a distributed aperture imagery with a lidar based fused 3D symbology. The combined system was evaluated in a simulator environment and on a vehicle based ground demonstrator for its capability to significantly mitigate DVE conditions, especially night level 5.

9471-15, Session 3

Seamless situational awareness

Howard W. Wiebold, Honeywell (United States)

The focus is providing pilots an edge in high-density, low-visibility operations. Of primary interest are taxi, takeoff, approach and landing operations, for which Honeywell is increasingly using designs that transform computationally intensive tasks into visually simple graphical solutions with displays and symbology that communicate directly with the visual cortex of the brain. The idea is to eliminate mental calculations that can delay action or prompt the wrong response.

The software suite includes prototype Primus Epic software, including 2-D and 3-D airport moving maps (AMM), cockpit display of traffic information (CDTI), Synthetic Visions Guidance System (SVGS) and a combined synthetic and infrared-based enhanced vision system (CVS). Applications will be available as options for the entire Primus Epic-based cockpits fleet as soon as 2016.

The approach is being tested in both commercial fixed wing aircraft and rotorcraft with plans for insertion into military rotorcraft. The combined synthetic vision system was the foundation for Honeywell's Synthetic Vision Avionics Backbone (SVAB) effort as part of the recently completed DARPA Multi-Function RF (MFRF) Technical Area 2.

9471-16, Session 4

Introduction of a 3D perspective view in the navigation display: featuring pilot's mental model

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

Synthetic vision systems (SVS) appear as spreading technology in the avionic domain. Several studies prove enhanced situational awareness when using synthetic vision. Since the introduction of synthetic vision (SV) aspects a steady change and evolution started concerning the primary flight display (PFD) and the navigation display (ND). The main improvements of the ND comprise the representation of the colored ground proximity warning (EGPWS), the weather radar, and the TCAS information. Before the integration into one multi-purpose display those safety critical systems have been scattered standalone systems in earlier avionics systems. Synthetic vision seems to offer high potential to further enhance cockpit display systems. Especially, concerning the current trend having a 3D perspective view in a SVS-PFD while leaving the navigational content as well as methods of interaction unchanged the question arouses if and how the gap between both displays might evolve to a serious problem. This issue becomes important in relation to the transition and combination of strategic and tactical flight guidance. Hence, pros and cons of 2D and 3D views generally as well as the gap between the egocentric perspective 3D view of the PFD and the exocentric 2D top and side view of the ND will be discussed. Further a concept for the integration of a 3D perspective view, i.e., bird's eye view, in synthetic vision ND will be presented. The combination of 2D and 3D views in the ND enables a better correlation of the SVS-ND and the SVS-PFD. Different views will show what the pilot will see in future outside and the SVS-PFD. Additionally, this supports the generation of pilots mental model . The authors believe it will improve the situational and spatial awareness during all flight regimes. It might prove to further raise the safety margin when operating in mountain areas.

9471-17, Session 4

Drift indication for helicopter approach and landing

Sven Schmerwitz, Patrizia M. Knabl, Thomas Lueken, Hans-Ullrich Doehler, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

Helicopter operations require a well-controlled and minimal lateral drift shortly before ground contact. Any lateral speed exceeding this small threshold can cause a dangerous momentum around the roll axis, which may cause a total roll over of the helicopter. As long as pilots can observe visual cues from the ground, they are able to easily control the helicopter drift. But whenever natural vision is reduced or even obscured, e.g. due to night, fog, or dust, this controllability diminishes. Therefore helicopter operators could benefit from some type of "drift indication" that mitigates the influence of a degraded visual environment.

With continuous technology advancement helmet-mounted displays (HMD) will soon become a spreading technology. At the present state those HMDs are still expensive and are mostly reserved for special military operations. The symbol sets implemented are designed for very specialized staff and again special missions. Investigating some of those symbol sets revealed that lateral drift indication doesn't live for what it promises.

Generally humans derive ego motion by the perceived environmental object flow. To enhance this perception a pattern motion was implemented in a conformal HMD symbol set which amplifies the measured own ship movement. The paper presents results from an experimental study with 18 pilots from civil and military operators. In this study the forward landing zone border was replaced by an animated dashed line for indicating the amplified ego motion.

9471-18, Session 4

Virtual aircraft-fixed cockpit instruments

Hans-Ullrich Doehler, Johannes M. Ernst, Thomas Lueken, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

The availability of new technologies for helmet- and head mounted displays facilitates the design of innovative cockpit layouts like a completely virtual flight deck. After the introduction of the so-called "glass cockpit", where formerly mechanical instruments have been converted digitally onto large panel screens, the virtual flight deck could be the logical next step into the future. Obviously, such a concept will save installation cost of conventional display hardware. Furthermore, and probably of greater importance, stressful and time-consuming accommodation changes for the pilots' eyes between outside- and inside-view can be avoided.

During the last months we have developed a concept for virtual cockpit instrumentation. Our implementation is based onto the "looking-through" JEDEYE™ monochrome green HMD, which offers a resolution of more than HD-TV, good enough to show detailed information as on presently installed head-down instruments. Our approach augments our latest "3D helicopter landing symbol format" with some basic virtual instruments (PFD, ND, knee-board) in the near field of the cockpit environment in "no-window" areas. Besides, we have implemented a "drag and drop" mechanism, which enables pilots to arrange instrumentation on their personal preference. Tests in our Generic Cockpit Simulator (GECO) are currently conducted. As first pilots' feedback show, our concept offers a great potential to be introduced into the future flight deck.

The contribution describes the basic principle of our approach and presents first pilots' feedback.

9471-19, Session 4

HMI aspects of the usage of ladar 3D data in pilot DVE support systems

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The paper discusses specifics of high resolution 3D sensor systems employed in helicopter DVE support systems and the consequences for the resulting HMI. 3D sensors have a number of specifics making them a cornerstone for helicopter pilot support or pilotage systems intended for use in DVE. Retrieving the depth information gives specific advantages over 2D imagers. On the other hand certain technology and physics inherent specifics require a more elaborate visualization procedure compared to 2D image visualization. The goal of all displayed information has to be to reduce pilots workload in DVE operations. Therefore especially for displaying the processed information on an HMD as 3D conformal data requires thorough HMI considerations.

9471-20, Session 5

Sensor modeling for precision ship-relative navigation in degraded visual environment conditions

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Unmanned aerial vehicles will soon become an integral part of the US Navy's operations, requiring these vehicles to be capable of taking off from and landing on ships at sea. Precision ship-relative navigation (PS-RN) in degraded visual environment conditions, possibly in the absence of GPS, is a key enabling technology to realize this capability. This paper describes the experimental modeling of vision and range sensors, including visible and IR cameras, scanning and flash lidar, and radar, with the ultimate purpose of developing sensor filtering techniques for the PS-RN problem. The sensors are modeled by (1) imaging a collection of standard targets and a scale ship deck under quantitatively measured, outdoor environmental conditions (clear, fog, rain, snow, etc.), (2) recording each sensor's response to the targets, and (3) determining each sensor's performance in the various conditions tested. The paper also describes the physical and software infrastructure of targets and ship deck built to support the modeling work, and directions for future work.

9471-21, Session 5

Real-time processing of dual-band HD video for maintaining operational effectiveness in degraded visual environments

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Effective reconnaissance, surveillance and situation awareness requires that salient features from dual band video are enhanced and presented to the user in a familiar manner. An optimum solution must consider the human visual requirement, while choosing signal processing algorithms that can be implemented efficiently. The resulting system must be inexpensive and low size, weight and power, while improving DRI, minimising operator fatigue and reducing reaction times in complex and highly dynamic situations. This paper begins with an overview of video fusion technology. The respective merits of competing approaches are discussed, with performance measured using a range of established metrics. Trials video is used to investigate the performance and robustness of candidate algorithms in diverse degraded visual environments. Subsequently, a system architecture and implementation based on the Xilinx Zynq 7020 system-on-a-chip (SoC) is presented. Bespoke firmware within the Artix-7 FPGA fabric of the device is used to accelerate computationally intensive operations, while the user interface, system configuration and flexible adaption are implemented using the embedded dual-core A9 ARM CPU. In addition to the high processing bandwidth facilitated by the Zynq 7020, the low power consumption makes the system appropriate for mobile, power critical, applications such as for UAVs and Special Forces. Results are presented for the platform, which demonstrate the exemplary performance, low processing latency and high power efficiency.

9471-22, Session 5

Mathematical principles of settings for extremely high resolution in multi beams systems

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Mathematical Principles of Settings and regularization method are compared in the modeling of multi beams measuring and signal processing systems. MPS gives us the invertible solutions with the controlled maximum precision and extremely high resolution. When the antenna pattern has the large side lobes or is the comb-beams we have the greater distortions in the receiving images from such Apparatus Functions. MPS gives us the corresponding resolving functions for inversion AF or compensation of distortion problem. Note in that instances, in addition we have resolving functions with the small norm or small reaction to noise. This is similar to the formation of images on the retina of the eye and in the brain. In regularization method we have the irreversible and smoothness solutions with the low precision. MPS extremely high resolution and regularization ultra resolution with 3D delta indication of object by point [1-2] are compared.

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Conference 9472: Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXI

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9472-1, Session 1

Chemical agent resistant coating (CARC) detection using hyperspectral imager (HSI)

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We are interested in detecting target materials potentially associated with the transport and handling of explosives and chemical and biological (CB) weapons, or non-traditional signatures of potential CB use that are more readily detected because of their size and environmental exposure, relative to the weapons materials themselves. Chemical Agent Resistant Coating (CARC) is the term for the paint commonly applied to military vehicles which provides protection against chemical and biological weapons. There are different CARC colors. In this paper, we present results for detecting CARC with two different colors (Green and Beige). A High-Fidelity Target Insertion Method has been developed. This method allow one to insert the target radiance into any HSI sensor scene, while still to preserve the sensor spatio-spectral noise at all the pixel positions. We show that the reduced (400-1,000nm) spectral range is good enough for Beige CARC, and Green CARC Type I and II detection. Different CARC types have been inserted to a DC Mall scene with the high fidelity target insertion tool. CARC detection has also been tested using real out-door measurements. All the tests showed promising CARC detection results using several current state-of-the-art HSI target detection methods such as Matched Filter (MF), Constrained Energy Minimization, Adaptive Coherence Estimator (ACE), Constrained Energy Minimization (CEM), and Spectral Angle Mapper (SAM).

Furthermore, we will present a newly developed Feature Transformation (FT) algorithm. In essence, the FT method, by transforming the original features to a different feature domain (e.g., the Fourier, wavelet packets, and local cosine domains), may considerably increase the statistic separation between the target and background probability density functions, and thus may significantly improve the target detection and identification performance, as evidenced by the test results in this paper. In our test, we used signatures for Green and Beige CARCs in original measured reflectance value units against 433 background material signatures that are frequently encountered such as paints, green trees and forests, metal, shingle, concrete, brick, sand, tar, asphalt, limestone, snow, and water, etc. In the original spectral feature domain, the Beige and Green CARC have large overlaps with the background materials/objects across the whole spectral bands (400nm–2500nm), leading to bad detection result. On the other hand, by observing the CARC and background signature curves, we noticed that the curve slops are quite different at a few spectral bands, and thus we have conducted a feature transformation by differentiating the originally measured reflectance features. We show that by differentiating the original spectral features (this operation can be considered as the 1st level Haar wavelet high-pass filtering), we can completely separate Beige CARC from the background using a single band at 645nm, and completely separate Green CARC from the background using a single band at 1180nm, leading to perfect detection results.

9472-2, Session 1

Metrics for the comparative evaluation of chemical plume identification algorithms

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Identification of chemical agents is a critical task of practical standoff chemical detection systems. In this paper, we develop a metric specifically adapted for evaluating chemical identifier performance and use it to compare several identification algorithms. In the system we analyze, a bank of single gas detectors passes hit pixels to the identifier, which produces a list of gases found in each pixel. Comparing the output to the truth in a confusion matrix describes in detail how the identifier performed. However, interpretation of the confusion matrix becomes difficult even for moderately sized gas libraries. We propose summarizing the confusion matrix using simple scalar metrics tailored for specific practical applications.

Ideally, an identifier should output exactly which gases are in the plume, but in many applications it is acceptable for the output to contain additional gases or lack some constituent gases. A performance metric should count these partially correct results with lower weights than completely correct results. The metric we propose, the Dice metric, weighs each result by its similarity with the list of gases in the plume, thereby giving less importance to partially correct outputs, while giving full scores only to exactly correct results.

Using the Dice metric we compared several algorithms including step-wise selection, a detector bank approach, Bayesian model selection, and Bayesian model averaging (BMA). Our analysis used data with real plumes as well as real background data with synthetically embedded plumes. In our experiments, we found that BMA performed well compared to other algorithms.

9472-3, Session 1

Pattern recognition in hyperspectral persistent imaging

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We give updates on a persistent imaging experiment dataset, being considered for public release in a foreseeable future, and present additional observations analyzing a subset of the dataset. The experiment is a long-term collaborative effort among the Army Research Laboratory, Army Armament RDEC, and Air Force Institute of Technology that focuses on the collection and exploitation of longwave infrared (LWIR) hyperspectral imagery. We emphasize the inherent challenges associated with using remotely sensed LWIR hyperspectral imagery for material recognition, and show that this data type violates key data assumptions conventionally used in the scientific community to develop detection/ID algorithms, i.e., normality, independence, identical distribution. We treat LWIR hyperspectral imagery as Longitudinal Data and aim at proposing a more realistic framework for material recognition as a function of spectral evolution through time, and discuss limitations. The defining characteristic of a longitudinal study is that objects are measured repeatedly through time and, as a result, data are dependent. This is in contrast to cross-sectional studies in which the outcomes of a specific event are observed by randomly sampling from a large population of relevant objects in which data are assumed independent. Researchers in the remote sensing community generally assume the problem of object recognition to be cross-sectional. But through a longitudinal analysis of a fixed site with multiple material types, we quantify and argue that, as data evolve through a full diurnal cycle, pattern recognition problems are longitudinal in nature and that by applying this knowledge may lead to better algorithms.

9472-5, Session 1

Burn injury diagnostic imaging device's accuracy improved by outlier detection and removal

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We utilized multi-spectral imaging (MSI) to develop a burn diagnostic device that would assist burn surgeons in planning and performing burn debridement surgery. In order to build a model, training data that accurately represents the burn tissue is needed. Acquiring accurate training data is difficult, in part because the labeling of raw MSI data to the appropriate tissue classes is prone to errors. We hypothesized that these difficulties could be surmounted by removing the outliers from the training dataset which would lead to an improvement in the classification accuracy. We developed a pig burn model to build an initial MSI training database and study our algorithm's ability to classify clinically important tissues present in a burn injury. Once the ground-truth database was generated from the pig images, we then developed a multi-stage method based on Z-test and univariate analysis to calculate outliers in our training dataset. Using 10-fold cross validation, we compared the algorithm's accuracy when trained with and without the presence of outliers. We demonstrated that our outlier removal method reduced the variance of the training data using the minimum covariance determinant estimator. Once outliers were removed from the training dataset, the averaging training accuracy improved from 72 to 90 %, and test accuracy improved from 63 to 76 %. Establishing this simple method of conditioning for our training data improved the accuracy of our algorithm to be as good as the current standard of care in burn injury assessment. Given that there are few burn surgeons and burn care facilities in the country; this technology is expected to improve the standard of burn care for burn patients with less access to specialized facilities.

9472-6, Session 1

Person detection in hyperspectral images via skin segmentation using an active learning approach

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Determining what hyperspectral image pixels belong to skin regions is a first necessary step in process of people detection in an image. Image segmentation is the process of partitioning visual data into meaningful pieces. It is one of the big challenges that remain open in computer vision. The performance of any method will be measured by comparing the segmentation results with that ideal segmentation created by the human. This approach is addressed in the literature as interactive image segmentation. This supervised machine learning problem can be addressed using Active Learning. It is a useful tool when dealing with data containing scarce labeled samples, making the application of conventional learning techniques based on a static dataset unusable. The methodology proposed on this article segments the image iteratively, not requiring the input of the user on every step. In our case, we previously labeled all the data manually. We have therefore assessed the validity of our method substituting the human interactor with an uncertainty-based query-by-commitee Active Learning setting. The algorithm uses an uncertainty measure as an indicator of which di cult pixels should it focus on the next iteration. The experimental framework presented in this article enabled the exploration of diverse computational aspects when dealing with skin detection. Firstly, it was shown that it is possible to segment skin in hyperspectral images, even in situations where noise is very present. Secondly, an Active Learning methodology was proposed to label and segment the images. Lastly, the accuracy of the proposed system was tested with varying image preprocessing steps.

9472-53, Session 1

Hyperspectral image-based methods for spectral biodiversity

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Hyperspectral images are an important tool to assess ecosystem biodiversity including terrestrial and benthic marine habitats. To obtain more precise analysis of biodiversity indicators that agree with indicators obtained using field data, improvements in spectral and spatial sensors resolution are needed. One of the advantages of developing more accurate analysis tools would be the extension of the analysis to larger zones using hyperspectral image processing. Another advantage is that it helps to plan more efficiently the collection of field data. The plant species richness is one of the most important indicators of biodiversity. This indicator can be measured in hyperspectral images considering the Spectral Variation Hypothesis (SVH), this states that the spectral heterogeneity is related to spatial heterogeneity and thus to species richness. The goal of this research is to capture spectral heterogeneity from hyperspectral images for terrestrial and benthic marine habitats using vector quantization (VQ) method and then use the result for prediction of plant species richness. The terrestrial habitats include all plant species in a chosen study site. Benthic marine habitats include all biological communities associated with the sea floor, from the top of the intertidal zone and inner reaches of estuaries down to the deep sea. The validation of the spectral index is done calculating the Pearson correlation coefficient between the Shannon entropy of actual field data and the Shannon entropy computed in the images using the vector quantization method. The experimental results for both cases show positive correlation between the Shannon entropy of the actual field data and the one computed using the proposed method.

9472-7, Session 2

Multi-pass encoding of hyperspectral imagery with spectral quality control

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Multi-pass encoding is a technique employed in the field of video compression that maximizes the quality of an encoded video sequence within the constraints of a specified bit rate. This paper presents research where multi-pass encoding is extended to the field of hyperspectral image compression. Unlike video, which is primarily intended to be viewed by a human observer, hyperspectral imagery is processed by computational algorithms that generally attempt to classify the pixel spectra within the imagery. As such, these algorithms are more sensitive to distortion in the spectral dimension of the image than they are to perceptual distortion in the spatial dimension. The compression algorithm developed for this research, which uses the Karhunen-Loeve transform for spectral decorrelation followed by a modified H.264/AVC encoder, maintains a user-specified spectral quality level while maximizing the compression ratio throughout the encoding process. The compression performance may be considered near-lossless in certain scenarios. For qualitative purposes, this paper presents the performance of the compression algorithm for several AVIRIS and Hyperion datasets using spectral angle as the spectral quality assessment function. Specifically, the compression performance is illustrated in the form of rate-distortion curves that plot spectral angle versus bits per pixel per band (bpppb).

9472-8, Session 2

SLIC superpixels for efficient graph-based dimensionality reduction of hyperspectral imagery

Xuewen Zhang, Selene E. Chew, Zhenlin Xu, Nathan D. Cahill, Rochester Institute of Technology (United States)

Dimensionality reduction is commonly applied to hyperspectral image data as a preprocessing step in algorithms for clustering, segmentation, classification, target detection, and anomaly detection. Nonlinear graph-based dimensionality reduction algorithms such as Laplacian Eigenmaps (LE) and Schroedinger Eigenmaps (SE) have been shown to be very effective at yielding low-dimensional representations that reflect the structure of the manifolds in high-dimensional space on which the original data reside. However, the steps of graph construction and eigenvector computation required by LE and SE can be prohibitively costly as the number of hyperspectral image pixels increases.

To address this computational burden, we propose pre-clustering the hyperspectral image into SLIC (Simple Linear Iterative Clustering) superpixels. Each superpixel may represent tens, hundreds, or even thousands of original image pixels. Performing LE or SE-based dimensionality reduction with the superpixels as input significantly reduces the computational effort required both for graph construction and for eigenvalue computation. However, it may come at the cost of generating low-dimensional representations that are inferior to those generated from all pixels if the superpixels are too large or regular to capture the heterogeneity present in the original data.

Using publicly available hyperspectral images (Indian Pines and Pavia University), we investigate this trade-off by exploring various choices of size/regularity parameters in the SLIC superpixels and their impact on (a) improvements in computational efficiency of the graph construction and eigenvector computation steps of LE and SE, and (b) potential reductions in accuracy or precision of subsequent SVM (Support Vector Machine) based classification of the image pixels using the resulting low-dimensional representations.

9472-9, Session 2

A concept for hyperspectral imaging with compressive sampling and dictionary recovery

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We postulate an optical configuration which takes a multispectral/hyperspectral scene and collects a multiplexed spectral sample on the Focal Plane Array (FPA). From such a measurement paradigm, the data is then processed with compressive imaging techniques and we recover the full multispectral cube from a single frame of imagery. We use a trained dictionary prior assumption along with a greedy reconstruction algorithm for local multispectral reconstruction.

9472-10, Session 3

Calculation of electronic-excited-state absorption spectra of water clusters using time-dependent density functional theory

Lulu Huang, Samuel G. Lambrakos, U.S. Naval Research Lab. (United States); Andrew Shabaev, George Mason Univ. (United States); Lou Massa, Hunter College (United States)

Calculations are presented of electronic-excited-state absorption spectra for molecular clusters of H2O using time-dependent density functional theory (TD-DFT). Calculation of excited state resonance structure using TD-DFT can provide interpretation of absorption spectra with respect to molecular structure for excitation by electromagnetic waves at frequencies within UV-visible range. The absorption spectrum corresponding to electronic excitation states of a molecular cluster consisting of a relatively small number of water molecules should be associated with response features that are intermediate between that of isolated molecules and that of a bulk lattice. TD-DFT calculated absorption spectra represent quantitative estimates that can be correlated with additional information obtained from laboratory measurements and other types of theory based calculations. The DFT software GAUSSIAN was used for the calculations of electronic excitation states presented here.

9472-11, Session 3

Comparison of microfacet BRDF model elements to diffraction BRDF model elements

Samuel D. Butler, Stephen E. Nauyoks, Michael A. Marciniak, Air Force Institute of Technology (United States)

Since the development of the Torrance-Sparrow bidirectional reflectance distribution function (BRDF) model in 1967, several models for BRDF have been developed. One of the most popular classes of BRDF models is the microfacet model, where physical optics effects are neglected, resulting in a simple approximation to the reflectance of realistic surfaces. However, this omission of physical optics does not lend well to BRDF applications in areas like Hyper-Spectral Imagery (HSI), where wavelength-dependent effects are critical to model. At the other extreme, physical optics models such as the Harvey-Shack model use diffraction theory to accurately predict the BRDF, but the calculation is time-consuming and requires detailed knowledge of the surface. In this paper, the two different approaches are compared in detail. The Harvey-Shack ? – ?0 space is compared to microfacet coordinates. Additionally, the Harvey-Shack model contains an energy conservation term (K), Fresnel term (Q), Power Spectral Density function to characterize the surface parameters, and other geometric and wavelength-dependent terms. These terms are compared to the microfacet model's main components: a simplified Fresnel reflection in microsurface coordinates, a conversion from scattering cross section to BRDF, the microsurface distribution function, and a geometric attenuation term. Similarities and differences in these terms are highlighted to bridge these disparate perspectives. It is hoped that such a comparison may generate ideas on how to develop BRDF models for applications such as HSI that balance the need for a simple, fast model with the requirement to more precisely account for physical optics effects such as wavelength scaling.

9472-12, Session 3

Development of land surface reflectance models based on multiscale simulation

Adam A. Goodenough, Scott D. Brown, Rochester Institute of Technology (United States)

Modeling and simulation of Earth imaging sensors with large spatial coverage necessitates an understanding of how photons interact with individual land surface processes at an aggregate level. For example, the leaf angle distribution of a deciduous forest canopy has a significant impact on the path of a single photon as it is scattered among the leaves and, consequently, a significant impact on the observed bidirectional reflectance distribution function (BRDF) of the canopy as a whole. In particular, simulation of imagery of heterogeneous scenes for many multispectral/hyperspectral applications requires detailed modeling of regions of the spectrum where many orders of scattering are required due to both high reflectance and transmittance. Radiative transfer modeling based on ray

tracing, hybrid Monte Carlo techniques and detailed geometric and optical models of land cover means that it is possible to build effective, aggregate optical models with parameters such as species, spatial distribution, and underlying terrain variation. This paper examines the capability of the Digital Image and Remote Sensing Image Generation (DIRSIG) model to generate BRDF data representing land surfaces at large scale from modeling at a much smaller scale. We describe robust methods for generating optical property models effectively in DIRSIG and present new tools for facilitating the process. The methods and results for forest canopies are described relative to the RAdiation transfer Model Intercomparison (RAMI) benchmark scenes, which also forms the basis for an evaluation of the approach. Additional applications and examples are presented, representing different types of land cover.

9472-13, Session 3

Advances in simulating radiance signatures for dynamic air/water interfaces

Adam A. Goodenough, Scott D. Brown, Aaron D. Gerace, Rochester Institute of Technology (United States)

The air-water interface poses a number of problems for both collecting and simulating imagery. At the surface, the magnitude of observed radiance can change by multiple orders of magnitude at high spatiotemporal frequency due to glinting effects. In the volume, similarly high frequency focusing of photons by a dynamic wave surface significantly changes the reflected radiance of in-water objects and the scattered return of the volume itself. These phenomena are often manifest as saturated pixels and artifacts in collected imagery (often enhanced by time delays between neighboring pixels or interpolation between adjacent filters) and as noise and greater required computation times in simulated imagery. This paper describes recent advances made to the Digital Image and Remote Sensing Image Generation (DIRSIG) model to address the simulation issues to better facilitate an understanding of a multi/hyper-spectral collection. Glint effects are simulated using a dynamic height field that can be driven by wave frequency models and generates a sea state at arbitrary time scales. The volume scattering problem is handled by coupling the geometry representing the surface (facetization by the height field) with the single scattering contribution at any point in the water. The problem is constrained somewhat by assuming that contributions come from a Snell's window above the scattering point and by assuming a direct source (sun). Diffuse single scattered and multiple scattered energy contributions are handled by Monte Carlo techniques employed previously. The model is compared to existing radiative transfer codes where possible, with the objective of providing a robust movel of time-dependent absolute radiance at many wavelengths.

9472-14, Session 3

Influence of density on hyperspectral BRDF signatures

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Recent hyperspectral measurements of composite granular sediments of varying densities conducted have revealed phenomena that contradict what radiative transfer theory would suggest (Bachmann et al., 2014). In high-density sands where dominant constituents are translucent and supplementary, darker grains are present, bidirectional reflectance distribution function measurements showed reduced intensity when compared to lower density counterparts. It is conjectured that this is due to the result of diminished multiple scattering from the darker particles which more optimally fill pore space as density increases. The goal of these experiments is to further expand upon these earlier results that were conducted primarily in the principle scattering plane and only at minimum and maximum density. In these studies the BRDF of granular composites is compared along a gradient of densities for optically contrasting materials. Systematic analysis of angular and material dependence will be used to determine the best means to better model multiple scattering effects of the granular materials. The measurements in this experiment will be taken using the newly constructed, laboratory and field-deployable Goniometer of the Rochester Institute of Technology (GRIT), which measures BRDF for geometries covering 360 degrees in azimuth and 65 degrees in zenith. In contrast to the previous studies limited to the principal scattering plane, GRIT provides a full hemispherical measurement.

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9472-15, Session 3

Development and comparison of data reconstruction methods for chromotomographic hyperspectral imagers

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Chromotomography is a form of hyperspectral imaging that uses a prism to simultaneously record spectral and spatial information, like a slitless spectrometer. The prism is rotated to provide multiple projections of the 3D data cube on the 2D detector array. Tomographic reconstruction methods are then used to estimate the hyperspectral data cube from the projections. This type of system can collect hyperspectral imagery from fast transient events, but suffers from reconstruction artifacts due to the limited-angle problem. Several algorithms have been proposed in the literature to improve reconstruction, including filtered backprojection, projection onto convex sets, subspace constraint, split-Bregman iteration and total variation. Here we present the first direct comparison of multiple different methods against measured and simulated data sets. Results are compared based on both image quality and spectral accuracy in the reconstruction, where the previous literature has emphasized imaging only. In addition, new algorithms and HSI quality metrics are proposed. We find the quality of the results depend strongly on the spatial and spectral content of the scene, and no single algorithm is consistently superior over a range of scenes.

9472-16, Session 4

Target detection assessment of the SHARE 2010/2012 hyperspectral data collection campaign

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It has been over four years (2010) since the first SpecTIR Hyperspectral Airborne Rochester Experiment (SHARE) was conducted. Similarly, a second SHARE experiment was performed, with the same HSI sensor, in 2012 with the exact same deployed target panels. A suite of sensors were flown over the target areas including multi- and hyperspectral imagers, as well as a LiDAR sensor. Experiments were conducted to examine topics such as pixel unmixing, subpixel detection, forest health, and in-water target detection, to name a few. This paper's focus is on target detection of different colored panels deployed on different backgrounds viewed under different illumination conditions collected two years apart. Detection includes utilization of LiDAR, reflectance and calibrated radiance imagery

with standard and non-standard detection schemes. Results are illustrated in the form of, detection maps, histogram plots (i.e., background vs. target scores) and ROC curves. Analysis was performed on (many) red and blue panels on backgrounds such as grass, gravel, and roof tar paper. The targets were in the open (i.e., fully illuminated), as well as heavy and light shadow. Discussion of where to obtain the free data is included.

9472-17, Session 4

An analysis task comparison of uncorrected vs. geo-registered airborne hyperspectral imagery

Yihang Sun, John Kerekes, Rochester Institute of Technology (United States)

The SHARE 2012 multisensor remote sensing data collection experiment provided an unprecedented set of freely available remote sensing data and ground truth for a variety of experiments. In particular, the subpixel detection and unmixing experiments provided the opportunity to test hyperspectral image detection and unmixing analysis algorithms and investigate quantitative performance on empirical data. In the case of the subpixel detection experiment, two sets of 50 subpixel objects were deployed to overcome limitations of small sample sizes occurring in previous empirical data collections. The unmixing targets were specifically designed to provide highly accurate truth of the endmembers and their pixel fractions, independent of the pixel sampling.

These data have been comprehensively analyzed to gain insight into achievable performance for subpixel detection and unmixing, and the sensitivity to many system and processing aspects. Results are presented for analysis choices such as which spectral bands and regions to use, whether or not to apply atmospheric compensation, which algorithms, source of target or endmember spectra, and the impact of georegistration. Insights into the impact on performance of these choices are presented.

In addition, this work has identified subsets of the overall data collection particular for these experiments. These subsets are being made available to the community for common research comparisons.

9472-18, Session 4

On the effects of spatial and spectral resolution on spatial-spectral target detection in SHARE 2012 and Bobcat 2013 hyperspectral imagery

Jason R. Kaufman, Exelis Space Computer Corp. (United States); Michael T. Eismann, Air Force Research Lab. (United States); Bradley M. Ratliff, Exelis Space Computer Corp. (United States); Mehmet Celenk, Ohio Univ. (United States)

During the SHARE 2012 campaign, the ProSpecTIR-VS sensor captured airborne visible to shortwave infrared (VIS/SWIR) hyperspectral imagery (HSI) over a set of specially-shaped vinyl tarp targets designed to support spatial-spectral algorithm development. A superset of these targets was later imaged by the Civil Air Patrol's Airborne Real-time Cueing Hyperspectral Enhanced Reconnaissance (ARCHER) sensor for the Bobcat 2013 collection, yielding coincident visible to near infrared (VNIR) hyperspectral and broadband visible high resolution imagery (HRI). ProSpecTIR-VS sampled a wider spectral range that was inclusive of ARCHER's at a higher rate than ARCHER over the spectral region common to both sensors. However, the ground sampling distance (GSD) of the Bobcat 2013 ARCHER imagery was 40cm while the SHARE 2012 ProSpecTIR-VS imagery's GSD was 100cm. Previous work with the Bobcat 2013 data set showed that increasing the apparent spatial resolution of VNIR HSI data led to better target separability in spatial-spectral feature spaces but did not consider the possible benefits of the SWIR portion of the spectrum. In this paper, we evaluate the tradeoffs in spatial and spectral resolution and spectral coverage between the two imagery collections for a common set of targets in terms of their effects on spatial-spectral target detection performance.

9472-19, Session 4

Locating the shadow regions in LIDAR data: results on the SHARE 2012 Dataset

Mustafa Boyaci, ASELSAN Inc. (Turkey); Seniha E. Yuksel, Hacettepe Univ. (Turkey)

In hyperspectral imaging, shadowy areas present a major problem as targets in shadow show decreased or no spectral signatures. One way to mitigate this problem is by the fusion of hyperspectral data with LIDAR data; since LIDAR data presents excellent information by providing elevation information, which can then be used to identify the regions of shadow. Although there is a lot of work to detect the shadowy areas, many are restricted to distinct platforms like ARGCIS, ENVI etc.

The purpose of this study is to (i) detect the shadow areas and to (ii) give a shadowiness scale in LIDAR data with Matlab in an efficient way. For this work, we designed our Line of Sight (LoS) algorithm that is optimized to run in a Matlab interface. The interface first converts the .las file format to the ASCII format. Then, it detects the shadows with an efficient Line of Sight (LoS) algorithm. The LoS algorithm uses the sun angles (altitude and azimuth) and elevation of the earth; and marks the pixel as "in shadow" if there lies an object of higher elevation between a given pixel and the sun. This is computed for all pixels in the scene and a shadow map is generated. Further, if a pixel is marked as a shadow area, the algorithm assigns a different darkness level which is inversely proportional to the distance between current pixel and the object that causes the shadow. With this shadow scale, it is both visually and computationally possible to distinguish the soft shadows from the dark shadows; an important information for hyperspectral imagery. The algorithm has been both tested on a synthetic dataset with objects of known heights, and also on the SHARE 2012 Avon AM dataset.

Our work is ongoing to match these shadowy regions to the hyperspectral images so as to show the effect of the scales of shadow on the spectral signatures.

9472-20, Session 4

Effect of endmember clustering on proportion estimation: results on the Share 2012 Dataset

Seniha E. Yuksel, Hacettepe Univ. (Turkey); Erdinc Gunes, ASELSAN Inc. (Turkey)

Estimating the number of endmembers and their spectrum is a challenging task. For one, endmember detection algorithms may over or underestimate the number of endmembers in a given scene. Further, even if the number of endmembers are known beforehand, result of the endmember detection algorithms may not be accurate. They may find multiple endmembers representing the same class, while completely missing some of the endmembers representing the other classes. This hinders the performance of unmixing, resulting in incorrect endmember proportion estimates.

In this study, only the SHARE-2012 AVON data pertaining to the unmixing experiment was considered, i.e., it was cropped to include only the eight pieces of cloth and a portion of the surrounding asphalt and grass. This data was used to evaluate the performance of five endmember detection algorithms, namely the PPI, VCA, N-FINDR, ICE and SPICE; none of which found the endmember spectra correctly. All of these algorithms generated multiple endmembers corresponding to the same class or they completely missed some of the endmembers. Hence, an algorithm was devised to group the endmembers of the same class so as not to over or under-estimate the true endmembers. The algorithms were run with twice the number of the true endmembers. Then, similar spectra based on the SAM distance were clustered together and a representative endmember was found for each class. These endmembers were (i) compared to the ground truth and (ii) also used in a quadratic unmixing algorithm and compared in terms of the performance in proportion estimation. Also, a further refinement was made by considering the spatial distances and eliminating the highly unused endmembers. The comparisons with or without this refinement for the five algorithms and the effect of the spatial corrections will be presented.

9472-21, Session 5

Incorporating signal-dependent noise for hyperspectral target detection

Christopher J. Morman, Russell C. Hardie, Univ. of Dayton (United States); Joseph Meola, Air Force Research Lab. (United States)

The majority of hyperspectral target detection algorithms are developed from statistical data models employing stationary background statistics or white Gaussian noise models. Stationary background models are inaccurate as a result of two separate physical processes. First, varying background classes often exist in the imagery that possess different clutter statistics. Many algorithms can account for this variability through the use of subspaces or clustering techniques. The second physical process, which is often ignored, is a signal-dependent sensor noise term. For photon counting sensors that are often used in hyperspectral imaging systems, sensor noise increases as the measured signal level increases as a result of Poisson random processes. In this work, a linear noise model is developed describing sensor noise variance as a linear function of signal level. The linear noise model is then incorporated for detection of targets using data collected at Wright Patterson Air Force Base.

9472-22, Session 5

Robust Chemical and Chemical-Resistant Material Detection Using Hyper-Spectral Imager and a New Bend Interpolation and Local Scaling HSI Sharpening Method

Hai-Wen Chen, Michael McGurr, Mark Brickhouse, Booz Allen Hamilton Inc. (United States)

Reliable chemical threat detection is critical for protecting our people from deadly chemical attacks. In this paper, we present new results from our ongoing research activity for chemical threat detection using hyper-spectral imager (HSI) detection techniques by detecting nontraditional threat spectral signatures of agent usage, such as protective equipment, coatings, paints, spills, and stains that are worn by human or on trucks or other objects. We have applied several current state-of-the-art HSI target detection methods such as Matched Filter (MF), Adaptive Coherence Estimator (ACE), Constrained Energy Minimization (CEM), and Spectral Angle Mapper (SAM). We are interested in detecting several chemical related materials: (a) Tyvek clothing is chemical resistance and Tyvek coveralls are one-piece garments for protecting human body from harmful chemicals, and (b) ammonium salts from background could be representative of spills from scrubbers or related to other chemical activities. The HSI dataset that we used for detection covers a chemical test field with more than 50 different kinds of chemicals, protective materials, coatings, and paints. Among them, there are four different kinds of Tyvek material, and three types of ammonium salts. The imagery cube data were collected by a HSI sensor with a spectral range of 400–2,500nm. Preliminary testing results are promising, and very high probability of detection (Pd) and low probability of false detection are achieved with the usage of full spectral range (400–2,500nm). We have also conducted target detection using reduced spectral range of 400-1,000nm. Although the performance (with 400-1,000nm) are worse than the performance with full spectrum (400-2,500nm), we can still successfully detect most of the Tyvek and ammonium salts with high Pd and low false detections.

9472-23, Session 5

An adaptive locally linear embedding manifold learning approach for hyperspectral target detection

Amanda K. Ziemann, David W. Messinger, Rochester Institute of Technology (United States)

Algorithms for spectral analysis commonly use parametric or linear models on the data. Research has shown, however, that hyperspectral data — particularly in materially cluttered scenes — are not always well-modeled by statistical or linear methods. Here, we propose an approach to hyperspectral target detection that is based on a graph theory model of the data and a manifold learning transformation. An adaptive nearest neighbor (ANN) graph is built on the data, and then used to implement an adaptive version of locally linear embedding (LLE). We artificially induce a target manifold and incorporate it into the adaptive LLE transformation. The artificial target manifold helps to guide the separation of the target data from the background data in the new, transformed manifold coordinates. Then, target detection is performed in the manifold space using a matched filter. This methodology is an improvement over previous iterations of this approach due to the incorporation of ANN, the artificial target manifold, and the choice of detector in the transformed space. We implement our approach in a spatially local way: the image is delineated into square tiles, and the detection maps are normalized across the entire image. Target detection results will be shown using laboratory-measured and scene-derived target spectra across two different hyperspectral data sets.

9472-24, Session 5

Ellipsoids for anomaly detection in remote sensing imagery

Guenchik J. Grosklos, James P. Theiler, Los Alamos National Lab. (United States)

For many target and anomaly detection algorithms, a key step is the estimation of a centroid (relatively easy) and a covariance matrix (somewhat harder) that characterize the background clutter. For a background that can be modeled as a multivariate Gaussian, the centroid and covariance lead to an explicit probability density function that can be used in likelihood ratio tests for optimal detection statistics. But ellipsoidal contours can characterize a much larger class of multivariate density function, and the ellipsoids that characterize the outer periphery of the distribution are most appropriate for detection in the low false alarm rate regime. Traditionally the sample mean and sample covariance are used to estimate ellipsoid location and shape, but these quantities are confounded both by large lever-arm outliers and non-Gaussian distributions within the ellipsoid of interest.

This paper compares a variety of centroid and covariance estimation schemes with the aim of characterizing the periphery of the background distribution. In particular, we will consider a robust variant of the Khachiyan algorithm for minimum-volume enclosing ellipsoid. The performance of these different approaches is evaluated on multispectral and hyperspectral remote sensing imagery using coverage plots of ellipsoid volume versus false alarm rate.

9472-25, Session 5

Video rate multispectral imaging for camouflaged target detection

Samuel T. Henry, Surface Optics Corp. (United States)

The ability to detect and identify camouflaged targets is critical in combat environments. Hyperspectral and Multispectral cameras allow a soldier to identify threats more effectively due to both increased color resolution and ability to see past visible light. Static imagers have proven success [1], however the development of a video rate imager allows for continuous real time target identification and tracking. This paper presents a video rate multispectral light field imager in the visible and near infrared (VNIR) range and discusses suitable detection algorithms. This allows for both automated detection of targets and interactive target tracking. The instrument and techniques are discussed and results are shown using a sample data set.

9472-26, Session 5

Evaluating backgrounds for subpixel target detection: when closer isn't better

Nofar Hasson, Shmual Asulin, Dan G. Blumberg, Stanley R. Rotman, Ben-Gurion Univ. of the Negev (Israel)

When performing hyperspectral subpixel detection, one wishes to estimate the spectral signature of the background; if we assume that the target is additive with the background, subtracting out the background will allow the target to remain with the noise.

The first step of target detection is the background estimation; in that phase we would like to estimate the value of the test pixel assuming it does not contain a target. The estimation would be based on the knowledge of the rest of the pixels in the image (assuming they do not contain a target) while ignoring the current value of the test pixel.

There exist many methods and algorithms in order to estimate a value of a single pixel; some of them are local using information from the pixels surrounding the tested pixel while others are non-local using information from the overall image in order to estimate the value of the requested pixel. It has been seen in previous studies that the local estimators can lead to very good results in the detection of point targets in hyperspectral images, but their efficiency is lowered in areas where two or more different materials meet1. These edge transition zones violate the basic assumption that the distribution of the pixels is stationary; the edges cause large difference between the values of neighboring pixels. The non-local estimators are believed to be able to overcome this difficulty because the estimation is based on pixels with similar surroundings to the examined pixel, which enables us to find similar edge areas and base the estimation on them.

In our research, we examined three different estimation methods, two local and one non-local. The local estimators are the mean and median; in those methods the estimated value for the test pixel is the mean or median (respectively) of its eight surrounding pixels. For the non-local estimator we used the K-patches algorithm3. In this method, we define a patch of a pixel by the NxN pixels surrounding it; we seek the K patches that are most similar to that of the tested pixel, where the similarity is base on the Euclidean distance. The estimation is then calculated by taking the mean of the K pixels whose patches were found to be the most suitable, in our implementation we used K=3 and N=3.

It is almost axiomatic that the better the estimate, the less noise is present and the easier it is to find the target. Little thought is made to the distribution of the noise since the inverse covariance matrix should convert this noise (if multi-variate normal) to an isotropic distribution. Nevertheless, in this paper, we will show that the distribution of the noise can be crucial for determining the efficacy of an estimator. In particular, the mean estimator will be superior to two other estimators when evaluating the background.

9472-27, Session 6

Spatial-spectral dimensionality reduction of hyperspectral imagery with partial knowledge of class labels

Nathan D. Cahill, Selene E. Chew, Paul S. Wenger, Rochester Institute of Technology (United States)

Dimensionality reduction algorithms have been used in a variety of hyperspectral imaging analysis applications to provide low-dimensional representations of the image data. Since the original image data may implicitly reside on a nonlinear manifold in a high-dimensional space, it is important that dimensionality reduction algorithms yield representations that preserve the structure of the manifold. Nonlinear dimensionality reduction algorithms such as Laplacian Eigenmaps (LE) and Schroedinger Eigenmaps (SE) are capable of integrating both the spatial and spectral information inherent in the image and have been shown to provide low-dimensional representations that can be effectively used as input for clustering, segmentation, and classification of hyperspectral imagery.

In this paper, we consider how to extend LE- and SE-based spatial-spectral dimensionality reduction algorithms to situations where partial knowledge of class labels exists, for example, when a subset of pixels has been manually labeled by an expert user. This partial knowledge is incorporated through the use of cluster potentials, turning each underlying algorithm into an instance of SE.

Using publicly available hyperspectral images (Indian Pines and Pavia University), we manually identify small subsets of pixels with ground-truth labels to be incorporated as partial knowledge in various spatial-spectral dimensionality reduction algorithms. With the resulting low-dimensional representations (generated both with and without the partial knowledge), we carry out Support Vector Machine (SVM) based classification to predict class labels for all pixels. Our analysis shows that incorporating partial knowledge of class labels in the low-dimensional representations yields classification results that are competitive with or superior to those based on using low-dimensional representations generated without partial knowledge.

9472-28, Session 6

Applications of direction-sensitive sparse representations to hyperspectral image analysis

Julia Dobrosotskaya, Case Western Reserve Univ. (United States)

As the modern signal acquisition techniques rapidly evolve, the methods of signal analysis and processing have to catch up - by accounting for multiple factors affecting the type and accuracy of the recorded signal representation, taking care of possible distortions or incompleteness, and utilizing signal redundancy whenever possible. Effective ways of data analysis require models that incorporate effective mathematical representation for multidimensional (and possibly heterogeneous data) and adaptive tunable tools with mimimal supervision.

Hyperspectral imagery analysis has benefited from a vast variety of mathematical approaches over the past decade. In this talk we discuss the possibilities of combining the classical hyperspectral methods with the advantages of multiscale directional sparse signal representations (such as composite wavelets) within adaptive computational models. The main goal in our model design is utilizing the edge and regularity information from 3D mutiscale sparse decomposition of the hyperspectral signals to modify and empower well-established hyperspectral classification and analysis methods without increasing their computational complexity.

9472-29, Session 6

Transitioning from semi-supervised to unsupervised feature extraction using Schrödinger Eigenmaps

Timothy Doster, U.S. Naval Research Lab. (United States)

Schrödinger Eigenmaps, first developed for the analysis of biomedical data, has recently been successfully applied to hyperspectral data for classification, segmentation, and target detection. This semi-supervised machine learning method, which can be characterized as a dimension reduction or feature extraction algorithm, builds upon Laplacian Eigenmaps by including semi-labeled data in a potential matrix. A difficulty, especially when dealing with large quantities of data, is the reliance on an expert to choose where to place potentials. We study here graph and information theoretic concepts as well as classical remote sensing image analysis techniques to choose autonomously where to place potentials and what the effect of the placement of these potentials has on the problems of classification, segmentation, and target detection. Specifically we examine: (1) the use of endmember selection algorithms to build potentials of pure or mixed pixels, (2) edge detection algorithms to build potentials to further separate adjacent classes, (3) potentials defined by local structures within patches to include spatial information, (4) wavelength ratio measures such as NVDI to create potentials from a priori spectral knowledge, (5) potentials constructed from purely linear feature extraction methods and (6) anomaly detection algorithms to mitigate anomalous pixel effects on manifold structure.

9472-30, Session 6

Detecting plumes in LWIR using robust nonnegative matrix factorization with graph-based initialization

Jing Qin, Univ. of California, Los Angeles (United States); Thomas Laurent, Loyola Marymount Univ. (United States); Kevin Bui, Univ. of California, Los Angeles (United States); Ricardo V. R. Tan, Jasmine Dahilig, Loyola Marymount Univ. (United States); Shuyi Wang, Univ. of California, Los Angeles (United States); Jared L. Rohe, Univ. of San Francisco (United States); Justin Sunu, California State Univ. (United States); Andrea L. Bertozzi, Univ. of California, Los Angeles (United States)

The detection of chemical gas plumes is of great importance in security and homeland defense, especially in cases of industrial accidents or terrorist attacks. Because chemical gases are diffusive and hard to observe in the visible spectrum, long-wave infrared (LWIR) hyperspectral imaging provides a means of detecting them. Since the obtained data is contaminated by excessive noise, it becomes challenging to generate a clear distinction between objects in a scene from hyperspectral imaging data. The processing of high-dimensional data increases computational complexity which requires efficient detection algorithms. In this paper, we propose a novel method relying on nonnegative matrix factorization (NMF) and graph-based algorithms to segment hyperspectral images. Because its optimization objective is highly non-convex, NMF is very sensitive to initialization. With a good initialization, it will however provide high quality segmentation results that are able to capture the more diffusive chemical gases due to its ability to separate different spectral signatures from objects in a hyperspectral image. We demonstrate how the graph-based algorithms, such as label propagation, spectral clustering and Nystrom extension, can be used to regularize the problem and provide good prior information to the NMF algorithm. We precede our method by applying Robust Principal Component Analysis (Robust PCA) to the raw images as a preprocessing step. Experimental results on real hyperspectral video sequence of chemical plumes show that the proposed approach is promising in terms of detection accuracy and computational efficiency.

9472-31, Session 6

Modeling and mitigating noise in graph and manifold representations of hyperspectral imagery

Charles M. Bachmann, Can Jin, Rochester Institute of Technology (United States)

Over the past decade, manifold and graph representations of hyperspectral imagery (HSI) have been explored widely in HSI applications. There are a large number of data-driven approaches to deriving manifold coordinate representations including Isometric Mapping (ISOMAP), Local Linear Embedding (LLE), Laplacian Eigenmaps (LE), Diffusion Kernels (DK), and many related methods. Improvements to specific algorithms have been developed to ease computational burden or otherwise improve algorithm performance. For example, the best way to estimate the size of the locally linear neighborhoods used in graph construction have been addressed as well as the best method of linking using the manifold representation with classifiers in applications. However, the problem of how to model and mitigate noise in manifold representations of hyperspectral imagery has not been well studied and remains a challenge for graph and manifold representations of hyperspectral imagery and their application. It is relatively easy to apply standard linear methods to remove noise from the data in advance of further processing, however, these approaches by and large treat the noise model in a global sense, using statistics derived from the entire data set and applying the results globally over the data set. Graph and manifold representations by their nature attempt to find an intrinsic representation of the local data structure, so it is natural to ask how can one best represent the noise model in a local sense. In this paper, we explore several approaches to modeling and mitigating noise at a local level.

9472-32, Session 6

Algorithms for retrieving temperature and emissivity from hyperspectral data in complex environments

Christoph C. Borel-Donohue, Air Force Institute of Technology (United States); Dalton S. Rosario, U.S. Army Research Lab. (United States); Joao M. Romano, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

This paper will use data measured under different weather conditions from a tower based at Picatinny arsenal in New Jersey. It will show the variability of the measured radiance with environmental changes and highlight the challenges this creates for retrieving desired quantities such as temperature and emissivity. Models that deal with reflections from the environment, e.g. nearby surfaces and the sky which maybe clear, partly cloudy or cloud covered will be used to try to retrieve spectral signatures. The effects of spectral resolution and instrument signal-to-noise ratio will be discussed.

9472-33, Session 7

Classification of multi-modality sensor data with limited labeled data

Melba M. Crawford, Purdue Univ. (United States); Saurabh Prasad, Univ. of Houston (United States); Hsiuhan Yang, Purdue Univ. (United States); Xiong Zhou, Univ. of Houston (United States); Zhou Zhang, Purdue Univ. (United States)

Classification of multi-sensor remote sensing data has been a topic of recent interest as complementary technologies have been developed, and data from advanced sensors are more widely available. Unfortunately, the performance of supervised learning models is heavily dependent on the

availability of representative labeled data for training, which are usually limited relative to the dimensionality of the data from multi-sensor systems. Active learning provides capability to exploit unlabeled samples, selecting, labeling, and inducting informative samples into the training set, but is computationally intensive. This research extends the traditional single sensor active learning strategy to a multi-sensor framework, where samples are selected for inclusion into the training set via multi-sensor, multi-scale criteria that exploit both pixel-level and local spatial information. The approach is demonstrated on a hyperspectral and LIDAR data set, using two strategies for representing spatial-spectral relationships: a Redundant Discrete Wavelet Transform decomposition and HSEG, and spatial-spectral segmentation, which are incorporated into an AL framework. Results are compared in terms of classification accuracy and computational overhead.

9472-34, Session 7

LWIR HSI target detection in the urban canyon

Amit Banerjee, Joshua B. Broadwater, Johns Hopkins Univ. Applied Physics Lab., LLC (United States)

There is an increase in ISR operations in urban areas, which are ideal battlefields for asymmetric threats to negate U.S. technological superiority. Many ISR sensors, including long-wave infrared (LWIR) hyperspectral imagers, require line-of-sight to the target, which is often difficult in an urban canyon. Furthermore, the LWIR spectra of targets are corrupted by downwelled radiation emitted by nearby objects such as buildings and trees. This downwelling phenomenon degrades the performance of LWIR HSI target detectors, leading to missed detections and high false alarm rates.

Recent work by Briottet [1] and Fontanilles [2] has focused on developing several mathematical and physical models for downwelling in urban canyon. This paper outlines one approach to incorporate these models into practical algorithms to detect targets in the presence of downwelling. Key steps in the approach include:

- Deriving first-order approximations to the latest models for thermal propagation in urban canopy developed in [1,2]

- Using these models to develop algorithms to predict or mitigate the effects of thermal downwelling on the target emissivity signature.

- Apply LWIR HSI detection algorithms using the modified target emissivity signature to evaluate target detection in open areas and urban canyons.

Results on real LWIR hyperspectral imagery using groundtruthed targets with and without downwelling are presented.

[1] X. Briottet, et al, “Intercomparison exercise of infrared radiative transfer models in the urban canopy.”

[2] G. Fontanilles, et al, “Aggregation process of optical properties and temperature over heterogeneous surfaces in infrared domain.”

9472-35, Session 7

Self-organization, neighborhoods, and possibilistic classification

Paul D. Gader, Leila Kalantari, Ron Fick, Univ. of Florida (United States)

Air and space borne imaging spectrometers produce images with measured spectra at each pixel. Materials in the measurement area can be classified to some degree of accuracy using only these spectra. Single pixels or aggregate measures of pixels (e.g. mean and variance of spectra measured on tree crowns) can be used as input data to a classifier. In any case, we think of classes as probability distributions and the input data as samples from those distributions. This is more for streamlining the discussion that follows rather than explicit use of probability distributions.

Air and space borne imaging spectrometers produce images with measured spectra at each pixel. Materials in the measurement area can be classified to some degree of accuracy using only these spectra. Single pixels or aggregate measures of pixels (e.g. mean and variance of spectra measured on tree crowns) can be used as input data to a classifier. In any case, we think of classes as probability distributions and the input data as samples from those distributions. This is more for streamlining the discussion that follows rather than explicit use of probability distributions.

There are two properties of classifiers that are important in fielded systems: (1) Robustness to operational outliers. Operational systems will almost certainly produce measurements on materials that are extremely unlikely to be generated by any of the classes used for training. (2) Ambiguity representation. Samples from different classes can be almost identical. This implies that the true class is not knowable using only the spectral measurements as presented. The classifier needs to properly represent the ambiguities in spectra in the hope that additional information can be used to resolve the ambiguity. In addition, classifications in operational systems are often part of a sequence of systems and do not make a final decision for all samples. Therefore, binary (0-1) outputs are inappropriate since information important for decision-making is lost. Operational classifiers produce values in the range [0,1] for each class so that class assignment, outlier confidence, and ambiguity can be represented by a uniform system. Possibility distributions (which are as rigorously defined as probability distributions) are well-suited for such representations.

Support Vector Machines (SVM) are often used for classification in remote sensing. SVM trained classifiers are very accurate when they are tested only on samples from classes that were used in training. Unfortunately, they are generally poor at outlier detection and ambiguity representation. In this talk, a number of approaches to real problems are presented. We show that the best approaches use self organizing feature maps (SOFM) and/or nearest prototype algorithms. This is analogous to learning a manifold and using local neighborhood information in feature space. We discuss these algorithms in the context of hyperspectral classification.

9472-36, Session 7

Schrodinger Eigenmaps for spectral target detection

Leidy P. Dorado-Munoz, David W. Messinger, Rochester Institute of Technology (United States)

Spectral imagery such as multispectral and hyperspectral data set could be seen as a set of panchromatic images stacked as a 3d cube, with two spatial dimensions and one spectral. For hyperspectral, the spectral dimension is highly sampled, which implies redundant information and a high spectral dimensionality. Therefore, it is necessary to use transformations on the data not only to reduce processing costs, but also to reveal some features or characteristics of the data that were hidden in the original space. Schrodinger Eigenmaps (SE) as a novel mathematical method for non-linear representation of a data set attempts to preserve the local structure while the spectral dimension is reduced. SE could be seen as an extension of Laplacian Eigenmaps (LE), where the diffusion process could be steered in certain directions determined by a potential term. SE was initially introduced as a semi supervised classification technique and most recently, it has been applied to target detection showing a promising performance. In target detection, only barrier potential has been used, so different forms to define barrier potentials and its influence on the data embedding are studied here. In this way, an experiment to assess the target detection vs. how strong it is the influence of potentials and how many eigenmaps are used in the detection, is proposed. The target detection is performed using a hyperspectral data set, and several targets and scenes with different complexity are also used, in order to have a wide framework of assessment.

9472-37, Session 7

Functions of multiple instances for sub-pixel target characterization in hyperspectral imagery

Alina Zare, Changzhe Jiao, Univ. of Missouri-Columbia (United States)

In this presentation, the Functions of Multiple Instances (FUMI) approach for learning target and non-target signatures is introduced. FUMI is a generalization of the Multiple Instance Learning (MIL) approach for supervised learning. FUMI differs significantly from standard MIL and supervised learning approaches because only data points which are functions of class concepts/signatures are available. In particular, this paper addresses the problem in which data points are linear combinations of target and non-target signatures. Multiple versions of the FUMI approach, including the Convex-FUMI (cFUMI) and Extended FUMI (eFUMI) algorithms are presented and applied to the problem of hyperspectral unmixing and sub-pixel target detection. cFUMI learns target and non-target signatures (i.e., target and non-target endmembers), the number of non-target signatures, and the proportion of each signature for every data point. The eFUMI algorithm extends cFUMI to allow for additional ``bag-level'' uncertainty in training labels. For these methods, training data need only binary labels indicating whether a data point (or some spatial area in the case of eFUMI) contains or does not contain some proportion of target; the specific target proportions for the training data are not needed. After learning the target signature using the binary-labeled training data, target detection can be performed on test data. Results for sub-pixel target detection on simulated and real airborne hyperspectral data are shown.

9472-38, Session 7

Anisotropic representations for superresolution of hyperspectral data

James M. Murphy, Wojciech Czaja, Daniel Weinberg, Edward Bosch, Univ. of Maryland, College Park (United States)

The analysis of hyperspectral imagery is a crucial problem at the intersection of the earth sciences, image processing, and applied mathematics. Often, hyperspectral images have poor resolution, due to sensor design or environmental effects. The technique of super-resolution improves the resolution of images by manipulating the image data, and is of great significance in the analysis of hyperspectral data.

We propose a novel technique for super-resolution, based on anisotropic representation systems in harmonic analysis. The recent innovations of shearlets and composite wavelets, which have strong directional sensitivity, shall be investigated. These representation systems are known to optimally represent edge-like features in images, and are thus natural candidates for super-resolution algorithms based on edge features. Our algorithms shall be compared to known super-resolution techniques based on wavelets.

9472-39, Session 8

The development of a DIRSIG simulation environment to support instrument trade studies for the SOLARIS sensor

Aaron D. Gerace, Jie Yang, Rochester Institute of Technology (United States); Joel McCorkel, NASA Goddard Space Flight Ctr. (United States)

NASA Goddard's SOLARIS (Solar, Lunar for Absolute Reflectance Imaging Spectroradiometer) sensor is the calibration demonstration system for CLARREO (Climate Absolute Radiance and Refractivity Observatory), a mission that addresses the need to make highly accurate observations of long-term climate change trends. The SOLARIS instrument will be designed to support a primary objective of CLARREO, which is to advance the accuracy of absolute calibration for space borne instruments in the reflected solar wavelengths. This work focuses on the development of a simulated environment to facilitate sensor trade studies to support instrument design and build of the SOLARIS sensor. Openly available data are used to generate geometrically and radiometrically realistic synthetic landscapes to serve as input to an image generation model, specifically the Digital Imaging and Remote Sensing Image Generation (DIRSIG) model.

Recent enhancements to DIRSIG's sensor model capabilities have made it an attractive option for performing sensor trade studies. This research takes advantage of these enhancements to model key sensor characteristics (e.g., sensor noise, relative spectral response, spectral coverage, etc.) and evaluate their impact on SOLARIS's stringent 0.3% error budget for absolute calibration. A SOLARIS sensor model is developed directly from measurements provided by NASA Goddard and various synthetic landscapes generated to identify potential calibration sites once the instrument achieves orbit. The results of these experiments are presented and potential sources of error for sensor inter-calibration are identified.

9472-40, Session 8

Empirical measurement and model validation of infrared spectra of contaminated surfaces

Sean Archer, Michael G. Gartley, John Kerekes, Rochester Institute of Technology (United States); Bogdon R. Cosofret, Jay P. Giblin, Physical Sciences Inc. (United States)

Liquid-contaminated surfaces generally require more sophisticated radiometric modeling to numerically describe surface properties. The Digital Imaging and Remote Sensing Image Generation (DIRSIG) Model utilizes radiative transfer modeling to generate synthetic imagery. Within DIRSIG, a micro-scale surface property model (microDIRSIG) was used to calculate numerical bidirectional reflectance distribution functions (BRDF) of geometric surfaces with applied concentrations of liquid contamination. Simple cases where the liquid contamination was well described by optical constants on optically flat surfaces were first analytically evaluated by ray tracing and modeled within microDIRSIG. More complex combinations of surface geometry and contaminant application were then incorporated into the micro-scale model. The computed microDIRSIG BRDF outputs were used to describe surface material properties in the encompassing DIRSIG simulation. These DIRSIG generated outputs were validated with empirical measurements obtained from a Design and Prototypes (D&P) Model 102 FTIR spectrometer. Infrared spectra from the synthetic imagery and the empirical measurements were iteratively compared to identify quantitative spectral similarity between the measured data and modeled outputs. Several spectral angles between the predicted and measured emissivity spectra differed by less than 1 degree. Synthetic radiance spectra produced from the microDIRSIG/DIRSIG combination had a RMS error of 0.21-0.81 watts/(m^2-sr-? m) when compared to the D&P measurements. Results from this comparison will facilitate improved methods for identifying spectral features and detecting liquid contamination on a variety of natural surfaces.

9472-41, Session 8

Spectral analysis of water samples using modulated resonance features for monitoring of public water resources

Samuel G. Lambrakos, U.S. Naval Research Lab. (United States); Constantine Yapijakis, The Cooper Union for the Advancement of Science and Art (United States); Daniel

Aiken, U.S. Naval Research Lab. (United States); Andrew Shabaev, George Mason Univ. (United States); Scott A. Ramsey, Joseph E. Peak, U.S. Naval Research Lab. (United States)

Hyperspectral analysis of water samples taken from public water resources in the New York City metro area, has demonstrated the potential application of this type of analysis for water monitoring, treatment and evaluation prior to filtration. Hyperspectral monitoring of contaminants with respect to types and relative concentrations requires tracking 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. To achieve this, it is necessary to establish correlation between hyperspectral signatures and types of contaminants to be found within specific water resources. Correlation between absorption spectra and changes in chemical and physical characteristics of contaminants requires sufficient sensitivity of spectral features with respect to these changes. The present study examines the sensitivity of modulated resonance features of spectra with respect to contaminant characteristics for hyperspectral analysis of water samples.

9472-42, Session 8

An accelerated line-by-line option for MODTRAN combining on-the-fly generation of line center absorption within 0.1 cm-1 bins and pre-computed line tails

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A Line-By-Line (LBL) option has been developed for MODTRAN6. The motivation for this development is two-fold. Firstly, when MODTRAN is validated against an independent LBL model, it is difficult to isolate the source of discrepancies. One must verify consistency between pressure, temperature and density profiles, between column density calculations, between continuum and particulate data, between spectral convolution methods, and more. Introducing a LBL option directly within MODTRAN will insure common elements for all calculations other than those used to compute molecular transmittances. Thus, the new option will facilitate testing and subsequent refinement of the MODTRAN band model.

The second motivation for the LBL upgrade is that it will enable users to compute high spectral resolution transmittances and radiances not only for the full range of current MODTRAN applications, but also for radiative transfer problems outside of current purview of MODTRAN. In particular, MODTRAN current applications include methods for solving the multiple scattering problem. Introducing the LBL feature into MODTRAN will enable first-principle calculations of scattered radiances, an option that is often not readily available with LBL models.

MODTRAN will compute LBL transmittances within one 0.1 cm-1 spectral bin at a time, marching through the full requested band pass. The LBL algorithm will use the highly accurate, pressure- and temperature-dependent MODTRAN Padé approximant fits of the contribution from line tails to define the absorption from all molecular transitions centered more than 0.05 cm-1 from each 0.1 cm-1 spectral bin. The beauty of this approach is that the on-the-fly computations for each 0.1 cm-1 bin will only require explicit LBL summing of transitions centered within a 0.2 cm-1 spectral region. That is, the contribution from the more distant lines will be pre-computed via the Padé approximants. The status of the LBL effort will be presented. This will include initial thermal and solar radiance calculations, validations against the LBLRTM model, and self-validations of the MODTRAN band model against its own LBL calculations.

9472-44, Session 8

Surface retrievals from Hyperion EO1 using a new, fast, 1D-Var based retrieval code

Jean-Claude Thelen, Stephan Havemann, Gerald J. Wong, Met Office (United Kingdom)

Here, we present a new prototype algorithm for the simultaneous retrieval of the atmospheric profiles (temperature, humidity, ozone and aerosol) and the surface reflectance from hyperspectral radiance measurements obtained from air/space-borne, hyperspectral imagers such as the 'Airborne Visible/Infrared Imager (AVIRIS) or Hyperion on board the Earth Observatory 1. The new scheme, proposed here, consists of a fast radiative transfer code, based on empirical orthogonal functions (EOFs), in conjunction with a 1D-Var retrieval scheme. The inclusion of an 'exact' scattering code based on spherical harmonics, allows for an accurate treatment of Rayleigh scattering and scattering by aerosols, water droplets and ice-crystals, thus making it possible to also retrieve cloud and aerosol optical properties, although here we will concentrate on non-cloudy scenes. We successfully tested this new approach using two hyperspectral images taken by AVIRIS, a whiskbroom imaging spectrometer operated by the NASA Jet Propulsion Laboratory.

9472-45, Session 9

Imaging polarization heterodyned interferometry using savart plates

Bryan D. Maione, Michael W. Kudenov, North Carolina State Univ. (United States)

Polarization spatial heterodyne interferometry (PSHI) allows for the development of compact, vibration insensitive, high spectral resolution sensors. Introducing the imaging qualities of a lenslet array extends the advantages of PSHI to imaging interferometers. The use of Savart plates enables a birefringent interferometer that obtains higher spectral resolution with fewer optical aberrations when compared to alternative designs. In this paper, we describe the design and Zemax-based simulation of an imaging polarization heterodyned interferometer (IPHI), based on Savart plates, along with its associated theoretical model. Additionally, we outline the preliminary results associated with its calibration. This sensor is advantageous for spectral imaging in the areas of remote sensing, biomedical imaging and machine vision.

9472-46, Session 9

Passive standoff imaging using spatial-spectral multiplexing

Ethan Woodard, Michael W. Kudenov, North Carolina State Univ. (United States)

The concept and model of a passive superresolution imaging system, with potentially unlimited spatial resolution, is detailed. While conventional lenses lead to diffraction limited systems with restricted spatial resolution, the described Spatial-Spectral Multiplexing (SSM) technique exploits a traditional Michelson interferometer (MI) and nonlinear dispersion characteristics to multiplex a scene's angular spectrum onto a scene's power spectrum. Conventional lenses create an image using transverse interference and are therefore fundamentally limited in spatial resolution. However, by multiplexing the transverse spatial information onto the longitudinal interference fringes of an optical beam, a detector can be used to measure the fringes, to a theoretically arbitrarily high precision, by adjusting the relative phase. To this end, a theoretical model of the MI-based system is developed and validated with data from proof of concept experiments. Additional modeling is incorporated to characterize non-ideal effects and to quantify the temporal, spatial, and spectral resolution tradespace of the system. Applications for this imaging system primarily include remote sensing and target identification, with future possibilities in medical or astronomical imaging depending on radiometric efficiency.

9472-47, Session 9

Automated turbulence and jitters correction with a dual port imaging Fourier-transform spectrometer

Florent M. Prel, Louis M. Moreau, 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 artifacts 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 an automated correction process based on the information provided by the second output port of a two-port imaging FTS. Corrected and uncorrected data will be compared.

9472-54, Session 10

Integrated visible to near-infrared, shortwave infrared, and longwave infrared spectral analysis for surface composition mapping near Mountain Pass, California

Meryl L. McDowell, Scitor Corp. (United States) and Naval Postgraduate School (United States); Fred A. Kruse, Naval Postgraduate School (United States)

The utility of visible to near infrared (VNIR), short wave infrared (SWIR) and long wave infrared (LWIR) spectral remote sensing for compositional analysis is well established, though not commonly used to full advantage. Most previous research and applications have focused on individual spectral ranges. We have developed new methods for enhanced identification and mapping that integrate VNIR-SWIR and LWIR multispectral and hyperspectral imagery, taking advantage of the complementary information available when the full range is considered.

The primary dataset used in this research combines hyperspectral Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data (VNIR-SWIR, 0.4 – 2.5 μm, 224 spectral bands) and multispectral MODIS/ASTER airborne simulator (MASTER) data (LWIR, 7.8 – 12.8 ?m, 10 spectral bands) of the Mountain Pass, California area. An additional dataset combining AVIRIS with the Aerospace Corporation's hyperspectral LWIR Mako instrument (7.6 – 13.2 μm, 128 spectral bands) was used to test the benefit of hyperspectral LWIR data. The VNIR-SWIR and LWIR spectra were corrected to surface reflectance and emissivity, respectively.

Spectral analysis was conducted in two main stages. An initial analysis was performed independently for each spectral range. The spectral and spatial dimensions were reduced using a minimum noise fraction transformation and "pure-pixel" extraction approach to select image endmembers, and a partial unmixing technique was used for abundance determination. Integrated analysis and classification were used in the second stage to produce a final map derived from the full spectral range. Analyses of the individual spectral ranges detect different materials, and integrated classification exhibits aspects from each range.

9472-55, Session 10

Exploration of integrated visible to near-, shortwave-, and longwave-infrared (full range) hyperspectral data analysis

Shelli R. Cone, Scitor Corp. (United States) and Naval Postgraduate School (United States); Fred A. Kruse, Naval Postgraduate School (United States); Meryl L. McDowell, Naval Postgraduate School (United States) and Scitor Corp. (United States)

Visible to near-, shortwave-, and longwave-infrared (VNIR, SWIR, LWIR) remote sensing data are typically analyzed in their individual wavelength regions, even though theory suggests combined use would emphasize complementary features. This research explored the potential for improvements in material classification using integrated datasets. Hyperspectral (HSI) VNIR and SWIR data from the MaRSuper Sensor System (MSS-1) were analyzed with HSI LWIR data from the Spatially Enhanced Broadband Array Spectrograph System (SEBASS) to determine differences between individual (baseline) and combined analyses. The first integration approach applied separate minimum noise fraction (MNF) transforms to the three regions and combined only non-noise transformed bands from the individual regions during analysis. The second approach integrated over 470 hyperspectral bands covering the VNIR, SWIR, and LWIR wavelengths before using MNF analysis to isolate linear band combinations containing high signal to noise. Spectral endmembers isolated from data were unmixed using partial unmixing. The feasible and high abundance pixels were spatially mapped using a consistent feasibility ratio threshold. Both integration methods enabled straight-forward and effective identification, characterization, and mapping of the scene because higher variability existed between endmembers and background. Results were compared to the baseline analysis. Material identification was more conclusive when analyzing across the full spectrum.

9472-56, Session 10

Analysis of multispectral and hyperspectral longwave infrared (LWIR) data for geologic mapping

Fred A. Kruse, Naval Postgraduate School (United States); Meryl L. McDowell, Naval Postgraduate School (United States) and Scitor Corp. (United States)

Multispectral MODIS/ASTER Airborne Simulator (MASTER) data and Hyperspectral Thermal Emission Spectrometer (HyTES) data covering the 8 – 12 micrometer spectral range (longwave infrared or LWIR) were analyzed for an area near Mountain Pass, California. Decorrelation stretched images were initially used to highlight spectral differences between geologic materials. Both datasets were then atmospherically corrected using the ISAC method, and the Normalized Emissivity approach was used to separate temperature and emissivity. The MASTER data had 10 LWIR spectral bands and approximately 35m spatial resolution and covered a larger area than the HyTES data, which were collected with 256 narrow (approximately 18nm-wide) spectral bands at approximately 2.3m spatial resolution. Spectra for key spatially-coherent, spectrally-determined geologic units for overlap areas were overlain and visually compared to determine similarities and differences. Endmember spectra were extracted from both datasets using n-dimensional scatterplotting and compared to emissivity spectral libraries for identification. Endmember distributions and abundances were then mapped using Mixture-Tuned Matched Filtering (MTMF), a partial unmixing approach. Multispectral results demonstrate separation of silica-rich vs non-silicate materials, with distinct mapping of carbonate areas. Hyperspectral results illustrate refined mapping of silicates with distinction between similar units based on the position, character, and shape of high resolution emission minima near 9 micrometers. Calcite and dolomite were separated, identified, and mapped using HyTES based on a shift of the main carbonate emissivity minimum from approximately 11.3 to 11.2 micrometers respectively. Both datasets demonstrate the utility of LWIR spectral remote sensing for geologic mapping.

9472-57, Session 10

Comparative analysis of Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), and Hyperspectral Thermal Emission Spectrometer (HyTES) longwave infrared (LWIR) hyperspectral data for geologic mapping

Fred A. Kruse, Naval Postgraduate School (United States)

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and Hyperspectral Thermal Emission Spectrometer (HyTES) data were used to map geology and alteration for a site in northern Death Valley, California and Nevada, USA. AVIRIS, with 224 bands at 10nm spectral resolution over the range 0.4 – 2.5 micrometers were converted to reflectance using an atmospheric model. Key mineral endmembers were extracted and identified, and their location and abundances were mapped. HyTES data with 256 bands at approximately 17nm spectral resolution covering the 8 – 12 micrometer range at 5m spatial resolution were atmospherically corrected using the empirical ISAC correction. These were further converted to approximate emissivity using an emissivity normalization temperature-emissivity separation approach. Spectral endmembers were again extracted and mapped. Field and laboratory spectral measurements of selected rock and alteration samples validate the AVIRIS and HyTES measurements. Spatial analysis of the distribution of endmembers separately mapped using the AVIRIS and HyTES data in geologic context illustrates that the HyTES endmembers are principally associated with primary rock forming silicates and carbonates while the AVIRIS endmembers mostly represent hydrothermal alteration. AVIRIS mapped clays, mica, sulfates, and silicification, and the difference between calcite and dolomite. HyTES was used to separate and map several igneous phases (not separable using AVIRIS) and to validate separation of calcite from dolomite. Together, these two datasets provide an improved picture of the distribution of geologic units and subsequent alteration and weathering. Combined, integrated analysis is in progress.

9472-48, Session 11

Symmetrized regression for multispectral background estimation

James P. Theiler, Brendt E. Wohlberg, Los Alamos National Lab. (United States)

We propose to improve the detection of targets and anomalies in a cluttered background by more effectively estimating that background. If one has a good estimate of what the target-free radiance should be at a pixel, that provides a point of comparison with the actual measured value at that pixel. Pixels with large discrepancies are candidates for target locations.

It is common to make this estimate using the mean of pixels in an annulus around the pixel of interest. But instead of the simple mean, one can employ more complicated functions that are learned from the rest of the image. Basically, this is a multivariate regression of the value at a central pixel as a function of the values of the pixels in the surrounding annulus. One can do this on a band-by-band basis, or with multiple bands simultaneously.

For overhead remote sensing imagery, there is an eightfold symmetry in the surrounding annulus, corresponding to reflection and rotation. Turning an image ninety degrees does not change its essential nature nor, to a good approximation, does it change its spatio-spectral statistics. (Nominally there is symmetry to arbitrary rotation, but the discreteness of square pixels limits the strict symmetry to rotations that are multiples of ninety degrees.) One can use this symmetry to effectively multiply the training set size by eight, or else one can impose symmetry on the feature set and thereby reduce the size of the training space. This paper will investigate the extent to which this symmetry can be exploited.

9472-49, Session 11

A comparison of directed search and in scene search target detection in Worldview-2 datasets

Stanley I Grossman, National Geospatial-Intelligence Agency (United States)

Since the events of September 11, 2001, the intelligence focus has moved from large order-of-battle targets to small targets of opportunity. This requires finer spectral and spatial fidelity to recognize those targets. This work hypothesizes that directed searches using calibrated data perform better than in-scene manually intensive target detection searches. Worldview-2 multispectral imagery was used with Non-conventional Exploitation Factors (NEF) data system generated signatures and standard detection algorithms to compare bespoke directed search capabilities against ENVI™ in-scene search capabilities. Multiple iterations were performed at increasing algorithm detection thresholds to generate detection rates. These rates are plotted and statistically analyzed. While individual head-to-head comparison results vary, 88% of the directed searches outperformed in-scene searches. When the results are averaged into meaningful groups, the generalized results universally indicate better directed search performance. The results strongly support the premise that directed searches out perform comparable in-scene searches.

9472-50, Session 11

Evaluation techniques and metrics for assessment of pan+MSI fusion (pansharpening)

Ryan A. Mercovich, Vencore, Inc. (United States)

Fusion of broadband panchromatic data with narrow band multispectral data – pansharpening – is a common and often studied problem in remote sensing. Many methods exist to produce data fusion results with the best possible spatial and spectral characteristics, and a number have been commercially implemented. This study examines the output products of 4 commercial implementations with regard to their relative strengths and weaknesses for a set of defined image characteristics and analyst use-cases. Image characteristics used are spatial detail, spatial quality, spectral integrity, and composite color quality, and analyst use-cases included a variety of object detection and identification tasks. The imagery comes courtesy of the RIT SHARE 2012 collect. Visual analyst evaluation results are compared with metric results to characterize the metrics and determine which are best suited to measure the defined image characteristics and image product use-cases. Because pansharpening represents a trade between adding spatial information from the panchromatic image and retaining spectral information from the MSI channels, the metrics examined are grouped into spatial improvement metrics and spectral preservation metrics. A single metric to quantify the quality of a pansharpening method would necessarily be a combination of weighted spatial and spectral metrics based on the importance of various spatial and spectral characteristics for the primary task of interest. Appropriate metrics and weights for such a combined metric are proposed here, based on the conducted analyst evaluation. Additionally, during this work, a new metric was developed specifically focused on assessment of spatial structure improvement relative to a reference image and independent of scene content. Using analysis of Fourier transform images a measure of high-frequency content is computed in small sub-segments of the image. The average improvement across the image is used as the metric, and the averaging across sub-segments combats the scene dependent nature of typical image sharpness techniques. This metric had improved dynamic range in the test set relative to other common spatial structure metrics.

9472-51, Session 11

Snapshot imaging Fraunhofer line discriminator for detection of plant fluorescence

Subharup Gupta Roy, Michael W. Kudenov, North Carolina State Univ. (United States)

Non-invasive quantification of plant health is traditionally accomplished using reflectance based metrics such as the normalized difference vegetative index (NDVI). However, measuring plant fluorescence (both active and passive) to determine photochemistry of plants has gained importance. Due to better cost efficiency, lower power requirements, and simpler scanning synchronization, detecting passive fluorescence is preferred over active fluorescence. In this paper, we propose a novel approach towards measuring plant fluorescence, within the hydrogen alpha Fraunhofer line at ~656 nm, using a Snapshot Imaging Fraunhofer Line Discriminator (SIFOLD). For the first time, the advantage of snapshot imaging for high throughput Fraunhofer Line Discrimination (FLD) is cultivated by our system, which is based on a multiple-image Fourier transform spectrometer and a spatial heterodyne interferometer (SHI). The SHI is a Sagnac interferometer, which is dispersion compensated using blazed diffraction gratings. We present data and techniques for calibrating the SIFOLD to any particular wavelength. This technique can be applied to quantify plant fluorescence at low cost and reduced complexity of data collection.

9472-52, Session 11

Assessing the impact of sub-pixel vegetation structure on imaging spectroscopy via simulation

Wei Yao, Jan A. N. van Aardt, Paul Romanczyk, David Kelbe, Martin van Leeuwen, Rochester Institute of Technology (United States)

Consistent and scalable estimation of vegetation structural parameters from imaging spectroscopy is essential to remote sensing for ecosystem studies, given the proven utility of such systems for more typical physiological assessments. The Hyperspectral Infrared Imager (HyspIRI) mission proposes an imaging spectrometer, which measures the 380-2500nm radiance in 10nm contiguous bands with 60m GSD. This platform is intended to function as a global imager, thus it would be beneficial to assess both vegetation physiology and structure from a single modality. This research therefore evaluates and attempts to confirm the link between vegetation structure and imaging spectroscopy.

To achieve the objective, three virtual scenes were constructed, which correspond to the actual vegetation structure of the National Ecological Observation Network (NEON) Pacific Southwest site (Fresno, CA). Secondly, the HyspIRI data (60m GSD) were simulated by the Digital Imaging and Remote Sensing Image Generation Model, a first-principles synthetic image generation model developed by the Rochester Institute of Technology. AVIRIS and NEON high-resolution spectrometer data were used to verify the geometric parameters and physical models. Thirdly, multiple simulated HyspIRI data sets were generated by varying within-pixel structural variables, such as forest density, the position and distribution of trees, crown size, etc. Finally, statistical significant differences among a series of narrow-band vegetation indices were used to assess the impact of sub-pixel vegetation structure on spectral response.

Early results indicate that HyspIRI is sensitive to sub-pixel vegetation structural variation in the blue and red spectral regions due to pigment changes, as well as the SWIR region due to water content variation. Therefore, the system's suitability for consistent global vegetation structural assessments could be improved by adapting calibration strategies to account for this sub-pixel variation. More detailed results will be presented at the conference.

9472-4, Session PSThu

Imaging white blood cells using a snapshot hyperspectral imaging system

Christopher J. Robison, Christopher J. Kolanko, Thirimachos Bourlai, Jeremy M. Dawson, West Virginia Univ. (United States)

A white blood cell count is used for detecting auto-immune symptoms, radiation/chemical exposure, or other health related issues in medical and point-of-care defense applications. This process often requires a significant amount of time, including physically drawing the blood and additional sample processing, such as staining. Methods of counting white blood cells on blood smear slides typically take from 15 min (in an emergency) up to 1 hour to complete in a lab setting and require a blood draw and sample staining. Snapshot Hyper-Spectral imaging systems are capable of capturing several spectral bands simultaneously, offering co-registered images of a target. With an appropriate optics, these systems are potentially able to image blood cells in vivo as they flow through a vessel, eliminating the need for a blood draw and sample staining. Our group has evaluated the capability of a commercial Snapshot Hyper-Spectral imaging system, the Arrow system from Rebellion Photonics, in differentiating between white and red blood cells both for traditional blood smear slides and blood samples sealed inside capillary tubes. We evaluated the imaging performance of the hyperspectral camera attached to a microscope at varying objective powers and illumination intensity. Hyperspectral data consisting of 40 hyperspectral bands with ~5nm spacing were captured over the range of 419 to 641nm. Open-source hyper-spectral data cube analysis tools, used primarily in Geographic Information Systems (GIS) applications, indicate that white blood cells features are most prominent in bands ranging from 428 to 442nm for blood samples viewed under 20x and 50x magnification over a varying range of illumination intensities. These images could potentially be used in subsequent automated white blood cell segmentation and counting algorithms for performing in vivo white blood cell counting.

9472-58, Session PSThu

Cooperative spectral and spatial feature fusion for camouflaged target detection

Sungho Kim, Min-Sheob Shim, Yeungnam Univ. (Korea, Republic of)

The detection of camouflaged objects is important for industrial inspection, medical diagnoses, and military applications. Conventional supervised learning methods for hyperspectral images can be a feasible solution. Such approaches, however, require a priori information of a camouflaged object and background. This paper proposes a fully autonomous feature selection and camouflaged object detectionmethod based on the online analysis of spectral and spatial features.The statistical distancemetric can generate candidate feature bands and further analysis of the entropy-based spatial grouping property can trim the useless feature bands.

In the first stage of spectral feature analysis, a new statistical distance measure in the ranking-based method instead of the band clustering method was proposed due to the high computational complexity. Spectral analysis can generate candidate bands that maximize the statistical distance. In the second stage, an entropy-based measure was proposed to quantify the uncertainty of spatial segmentation. The bands that generate high entropy value (noisy spatial segmentation) can be reduced. Therefore, the first contribution is the proposition of a novel band selection method by considering both spectral and spatial analysis without prior knowledge. The second contribution is the automatic detection of a camouflaged or abnormal region without a training process. Therefore, the detected results can be obtained without human intervention if any kinds of hyperspectral test images are applied to the inspection system. Camouflaged objects can be detected better with less computational complexity by optical spectral-spatial feature analysis.

9472-59, Session PSThu

On the response function separability of hyperspectral imaging systems

Jurij Jemec, Univ. of Ljubljana (Slovenia); Franjo Pernuš, Boštjan Likar, Univ. of Ljubljana (Slovenia) and Sensum d.o.o. (Slovenia); Miran Bürmen, Univ. of Ljubljana (Slovenia)

Hyperspectral imaging is a 3D imaging modality comprising one spectral and two spatial dimensions. Hyperspectral imaging systems consist of three main units: the front lens, the light-diffraction element and a camera. Imperfections in these components introduce spectral and spatial dependent distortions in the recorded 3D image. These can be characterized by a 3D response function that is subsequently used to remove distortions and enhance the resolution of the recorded images by deconvolution. The majority of existing characterization methods assume spatial and spectral separability of the 3D response function. In this way, the complex problem of 3D response function characterization is reduced to independent characterization of the three orthogonal response function components. However, if the 3D response function is non-separable, such characterization can lead to poor results of the deconvolution-based image enhancement. In this paper, we examine the separability of the 3D response function in the spatial plane. A direct measurement procedure is used to estimate the spatial 2D response function. To study the effect of non-separability on the quality of deconvolved images, deconvolution with separable and non-separable response function estimates obtained in the characterization process is performed on a set of recorded test images. The quality of deconvolved images is assessed in terms of rise width and step edge overshoot in the images after performing deconvolution. Results indicate that there are cases, when non-separability of the system response function should be considered.

9472-60, Session PSThu

Evaluation of rainfall and NDVI anomalies using distributed lag models

Worku Zewdie Gebrehiwot, Elmar Csaplovics, Technische Univ. Dresden (Germany)

Climatic variability and human impacts have caused major environmental changes in the sub-Saharan Africa. The semiarid regions of northwestern Ethiopia are exposed to this anthropogenic and natural calamity. There is a cloud of haze originating in the border of Sudan and Ethiopia resulted from land degradation.However the extent and degree of changes were not thoroughly analyzed.In this study we assessed the relationship between Tropical Applications of Meteorology using Satellite data(TAMSAT) rainfall data and Moderate Resolution Imaging Spectroradiometer(eMODIS) Normalized Difference Vegetation Index (NDVI) data for the period from 2000 to 2014 on decadal and annual basis using multivariate distributed lag (DL) models.The decadal growing seasons (June to September) values were calculated from MODIS NDVI data. A regression analysis using DL model was performed to evaluate time-lagged effects of rainfall amount and mean surface temperature on the biomass productivity. The growing season NDVI values are highly correlated with the precipitations during the whole study period. A lag of up to 30 days observed in most parts of our study region. The higher lagged correlation was observed in woodland regions that suffered a severe deforestation due to cropland expansion and population growth. The loss in vegetation cover contributed to low biomass production due to extended loss in vegetation cover. In spite of the effects of climatic factors, the impact of human activities is a significant contributor for changes of environment and vegetation loss.

9472-61, Session PSThu

Skin detection in hyperspectral imagery

Stephanie M. Sanchez, Miguel Velez-Reyes, The Univ. of Texas at El Paso (United States)

Hyperspectral imagers collect information of the scene being imaging at nearly contiguous bands in the electromagnetic spectrum at high spectral resolution. Hyperspectral images are organized in a data cube where the x and y axes contain spatial information and the z-axis spectral information. These imagers are use in various application fields (i.e. agriculture, surveillance, chemical imaging, environmental, medical, etc.). Combining hyperspectral imaging with skin optics principles will allow detection of human's presence in a scene based on skin detection. Due to similarity of skin pigmentation to several objects, standard three band digital RGB cameras are sometimes unable to detect skin and non-skin accurately, as false alarms typically appear with objects that have colors similar to skin tones.

In our work, we study published and develop feature extraction methods that are focused on skin detection over different background using hyperspectral imaging. Spectral signatures in the 400 to 2500 nm spectral region are collected from skin and different objects with a spectrometer and used to create a database to evaluate the performance of different features. Hyperspectral images in the 400 to 1000 nm spectral region with people over different backgrounds are collected and used to test the proposed features. Data is analyzed using the MATLAB software. A new normalized differential index is proposed using bands around 800 nm and 980 nm. Results from spectral analysis show that combinations of different normalized indexes have different discrimination performance for the proposed skin detection task.

9472-62, Session PSThu

Can we match ultraviolet face images against their visible counterparts?

Neeru Narang, Thirimachos Bourlai, West Virginia Univ. (United States); Lawrence A Hornak, University of Georgia (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. However, face recognition (FR) for face images captured from different camera sensors, illumination conditions, and expressions is very challenging. In this paper, we investigate the advantages and limitations of the heterogeneous problem of matching ultra violet (from 10 nm to 400 nm in wavelength) or UV, face images against their visible counterparts, when all face images are captured under controlled conditions.

The contributions of our work are three-fold; (i) We used a camera sensor designed with the capability to acquire UV images at short-ranges, and generated a dual-band (Visible and UV) database that is composed of multiple, full frontal, face images of 50 subjects. Two sessions were collected that span over the period of 2 months. (ii) For each dataset, we determined which set of face image pre-processing algorithms are more suitable for face matching, and, finally, (iii) We determined which FR algorithm better matches cross-band images, resulting in high rank-1 identification rates. Experimental results show that our cross spectral matching (the heterogeneous problem, where gallery and probe sets have face images acquired in different spectral bands) algorithms achieve sufficient identification performance. However, we also conclude that the problem under study, is very challenging, and it requires further investigation to address real-world law enforcement or military situations. To the best of our knowledge, this is first time in the open literature the problem of cross-spectral matching of UV against VIS band face images is being investigated.

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9473-1, Session 1

Streaming analysis of track data from video

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A vast amount of temporal information are collected and stored, which calls for techniques to extract useful high-level information, such as recognizable activities or events. This paper proposes a framework for streaming analysis of time series data, in this case track data from video sequences, which can recognize events without supervision and memorize them by building the temporal contexts. The memorized historical data is then used to predict the future and detect anomalous activities or events. An incremental clustering method is used to recognize and learn the event without training. A memorization method of double localization, including relative and absolute localization, is proposed to model the temporal context. The first-order Markov chain is used as an example to relatively localize an event in the temporal space, while a temporal map is used to absolutely localize an event. By setting proper coordinates for the temporal map, prior temporal patterns can be included before building more delicate models to find subtle patterns. Finally, the predictive model is built based on the method of memorization. The “Edinburgh Informatics Forum Pedestrian Data set”, which offers about 1000 observed trajectories of pedestrians detected in camera images each working day for several months, is used as an example to illustrate the framework. The trajectories are incrementally recognized as activities, and the activities are further used to describe the situation (event) in the scene. By using the proposed framework, we not only get current high level information of the scene, such as activities and events occurring in the scene, but also we can reason whether current activities or events are normal by referring to the temporal context learned from historical data. In the end, a total of 92,000+ observed trajectories and their temporal patterns over one year can be summarized by a temporal map of 16 events and a probability (transition) matrix between them. Our proposed framework offers an effective method of extracting useful and manageable information from a huge amount of raw data trajectories.

9473-2, Session 1

Illumination robust change detection with CMOS imaging sensors

Vijay Rengarajan, Sheetal B. Gupta, Ambasamudram N. Rajagopalan, Indian Institute of Technology Madras (India); Gunasekaran Seetharaman, Air Force Research Lab. (United States)

Change detection between two images in the presence of degradations is an important problem in the computer vision community, more so for the aerial scenario which is particularly challenging. Cameras mounted on moving platforms such as aircrafts or drones are subject to general six-dimensional motion as the motion is not restricted to a single plane. With CMOS cameras increasingly in vogue due to their low power consumption, the inevitability of rolling-shutter (RS) effect adds to the challenge. This is caused by sequential exposure of rows in CMOS cameras unlike conventional global shutter cameras where all pixels are exposed simultaneously. The RS effect is particularly pronounced in aerial imaging since each row of the imaging sensor is likely to experience a different motion. For fast-moving platforms, the problem is further compounded since the rows are also affected by motion blur. Moreover, since the two images are shot at different times, illumination differences are common. In this paper, we propose a unified computational framework that elegantly exploits the sparsity constraint to deal with the problem of change detection in images degraded by RS effect, motion blur as well as non-global illumination differences. We formulate an optimization problem where each row of the distorted image is approximated as a weighted sum of the corresponding rows in warped versions of the reference image due to camera motion within the exposure period to account for geometric as well as photometric differences. The method will be validated on synthetic and real data.

9473-3, Session 1

Cueing motion blur for registration of inclined planar scenes

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Motion blur is an omnipresent phenomenon observed in most images we capture in low-light conditions, or with light-weight cameras mounted on moving platforms. While existing methods that deal with motion blur typically assume a fronto-parallel scene, this need not always be the case, especially in applications such as remote sensing. While most methods treat motion blur as nuisance, we show how the blur itself can be harnessed as a cue to infer the normal of the plane. We then show how this information can be incorporated in the important low-level vision task of change detection with respect to a reference image. The interesting and novel challenge we tackle in our work is that the blurred image can correspond to any unknown inclination depending on the relative orientation of the camera with respect to the scene. The proposed method mainly comprises of two stages. In the first stage, we determine the orientation of the plane from the motion-blurred image by establishing correspondences among the extremities of the blur kernels at different locations in the image. In the second stage, we identify the changes with respect to the reference image by employing a projective motion blur model which also factors-in the estimated normal of the plane. After reorientation, we employ a reblur-difference framework to detect the occlusions. In the experimental section, we validate our method on synthetic as well as real images along with comparisons to the state-of-the-art.

9473-4, Session 1

Object and activity detection from aerial video

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Aerial video surveillance has advanced significantly in recent years, as inexpensive high-quality video cameras and airborne platforms are becoming more readily available. Video has become an indispensable part of military operations and is now becoming increasingly valuable in the civil and paramilitary sectors. Such surveillance capabilities are useful for battlefield intelligence and reconnaissance as well as monitoring major events, border control and critical infrastructure. However, monitoring such growing flood of video data requires significant effort from increasingly large numbers of video analysts.

We have developed a suite of aerial video exploitation tools that can alleviate mundane monitoring from the analysts, by detecting and alerting objects and activities that require analysts’ attention. These tools can be used for both tactical applications and post-mission analytics, so that the video data can be exploited more efficiently and timely.

A feature-based approach and a pixel-based approach have been developed for Video Moving Target Indicator (VMTI) to detect moving objects at real-time in aerial video. Such moving objects can then be classified by a person detector algorithm which was trained with representative aerial data. We are also developing an activity recognition tool that can recognize activities of interests in aerial video, such as person-vehicle interaction.

We have implemented a flexible framework so that new processing modules can be added easily. The Graphical User Interface (GUI) allows the user to configure the processing pipeline at run-time to evaluate different algorithms and parameters. Preliminary results are promising and more detailed performance evaluation is on-going.

9473-5, Session 1

Application of VNIIRS for target tracking

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The Motion Imagery Standards Board (MISB) has created the Video National Imagery Interpretability Rating Scale (V-NIIRS). VNIIRS extends NIIRS to scene characterization from streaming video to include object recognition of various targets for a given size. To apply VNIIRs, there is a need to understand the operating conditions of the sensor type, environmental phenomenon, and target behavior (SET). Given the general definitions of NIIRS, there is a need to understand the approach towards rating the ability of target tracking methods to instantiate the method. In this paper, we explore VNIIRS for different target tracking techniques given the resolution of the sensor that supports the relative performance of the sensor to target resolution in the image. The relative assessment can be used in relation to the absolute target size associated with the VNIIRS. In a notional analysis, we determine the issues and capabilities of using VNIIRS in rating the performance of methods to achieve the various ratings. The outcome of the study is an experiment to understand how to use VNIIRS as method of target tracking evaluation

9473-6, Session 1

AESOP: adaptive event detection software using programming by example

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Currently, human operators must closely monitor video for simultaneous situational awareness and threat assessment.

Environments in a state of constant activity generate numerous visual cues, each of which must be examined so that potential security breaches do not go unnoticed.

The need for constant vigilance places a significant burden on the operator, invariably leading to fatigue and lapses in attention span.

Previous event recognition approaches relied on change detection algorithms to identify pixels that differ between successive frames in the image sequence.

These algorithms do not model the nuances of object interaction required for robust event detection.

In addition, these algorithms were designed for applications involving minimal camera motion.

Changes in, viewing angle, scale, and illumination present additional complexity; currently, systems cannot reconcile the same scene viewed from different vantage points.

Therefore, an adaptive system that can detect events of interest automatically regardless of operating scenario is necessary for addressing these issues.

This paper introduces AESOP (Adaptive Event detection SOftware using Programming by example), a video event detection software tool that automatically detects time-critical events in real time.

The system learns new events using a programming by example paradigm.

With this technique, an analyst teaches the software tool new events by demonstrating actions on concrete examples.

During the training phase, an analyst defines the attributes that constitute an event of interest in the video.

The attributes include the actors (or targets) and the time duration of the event.

The system analyzes the targets over the duration of the event to generate a set of characteristic features that describe the event.

These features yield a time-series representation of the orientation and velocity of targets in relation to other targets.

A machine learning algorithm then learns event models from these features.

Once trained, the system processes incoming video and identifies user-defined events in real time while also indexing the video to simplify forensic analysis.

The online event detection software is comprised of algorithms for video stabilization, target detection, target tracking and event detection.

The video stabilization algorithm registers successive video frames using planar homography.

The is effective for aerial video sequences in both land and maritime scenarios.

Target detection is accomplished using model-free and model-based methods.

Model-free methods include motion segmentation algorithm to segment an image into regions such that the motion of all pixels (optical flow) within a region is consistent.

Model-based methods train an object detector to distinguish objects of interest from background structures.

Given target detections, the multi-target tracking algorithm uses a data-association approach to produce long duration trajectories by temporally sequencing the per-frame detections.

Dynamic Time Warping (DTW) and Hidden Markov Model (HMM) approaches are formulated for modeling spatio-temporal events.

DTW relies on matching incoming trajectory sequences with examples in the training set while the HMM computes a succinct probabilistic representation for each event class.

HMM's advantages over DTW include the ability to generalize to unseen scenarios and the ability to model complex and composite events.

The performance of event detection approaches are evaluated on standard datasets (e.g., VIVID, VIRAT) as well as on data collected in-house.

Promising event detection results are demonstrated on maritime sequences collected from a point-tilt-zoom camera installed on a FireScout UAV.

In addition to real-time monitoring for improved situational awareness, the system can also be employed in forensic applications where the software can quickly search a large video archive for specific events of interest.

9473-7, Session 1

Textured object video segmentation using temporal coherency

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Deformable and articulated objects are hard to segment and track over time. Purely motion based techniques such as optical flow can produce good results in terms of segmenting motion, however they do not incorporate salient object features. In this work, we propose a textured object segmentation method using temporal coherency in videos. We utilize color and texture feature fusion within a fast globally convex active contour method to obtain multi-scale intra frame segmentations. A long distance optical flow based point trajectories is then combined with frame

segmentations to obtain label propagation along the temporal direction. Total variation regularization is applied to obtain well-defined object boundaries and a dual minimization implementation is undertaken for solving the overall energy minimization. Experimental results are given to highlight our method and shows that we obtain dense segmentations even with sparse and noisy initial label set.

9473-8, Session 2

Pedestrian dead reckoning using a novel sensor module that interfaces with modern smart devices

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Tracking individuals in areas such as dense urban environments and building interiors is desirable for numerous critical applications, but has been problematic mainly because of the unreliability or unavailability of GPS in many locations of interest. To date, tracking applications that utilize the inertial sensors on a smart device (i.e., pedestrian dead reckoning) have had varied degrees of success: accuracy typically dips below that of standard GPS within minutes and depends strongly on the quality of the sensors in the device, as well as the location that the device is carried on the body. To address these issues, in this paper we present a sensor module that interfaces with any modern smart device and which utilizes an innovative 'dual 9-axis IMU', a pressure sensor, and an ultra-high sensitivity GPS receiver to provide an advanced pedestrian dead reckoning solution. The sensor module is designed to communicate with a smart device (e.g., iOS, Android or Windows) via the audio jack and is intended to be belt-mounted or located in the pocket of the user. In addition to describing the sensor module's hardware and functionality, we present our approach to processing the sensor module's data streams to determine a user's real-time position. Results for the prototype sensor module, tested in operationally relevant scenarios, will also be presented and discussed.

9473-9, Session 2

Information fusion performance evaluation for motion imagery data

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As technology and internet usage grows at exponential rates; video and imagery data has become increasingly important for security, surveillance, and response recovery. Wide Area Motion imagery (WAMI), Full Motion Video (FMV), and Hyper Spectral Imaging (HSI) are data sources that are collected as still or motion imagery. The imagery, along with extracted relevant information provides contextual updates. Computer vision exploitation applications include detecting and identifying a particular object in imagery data which is useful for content based image retrieval (CBIR). For example, finding all video clips that contain a certain object (e.g., garden rake), or classes of people, automobiles, buildings, would be desirable. Each imagery data is segmented, automatically analyzed and stored in a dynamic and robust database. Blasch et al. proposed an Artificial Intelligence based event-Modeling and Video Imagery Segmentation (AIM-VIS) methodology which will fulfills the urgent need of building a common and imagery database. The AIM-VIS dynamic database will further support Information Fusion (IF) methods). Many IF algorithms have been proposed based on different assumptions such as statistical, Gaussian, MinMax distributions, but only few metrics are used to evaluate the performance of these algorithms. In this paper, we propose a robust novel objective metric to evaluate the performance of image fusion which compares the outcome of a given algorithm with ground truth along with several types of errors. The main feature of this proposed methodology is as follows: given the ground truth of motion imagery data, AIM-VIS will compute detection failure, false alarms, background, foreground regions, split of foreground regions, and merge of foreground regions. AIM-VIS will then compute statistics such as Mutual Information (MI), entropy, Structural Similarity Index (SSIM) for each of the above said errors in multiscale fashion. The segmentation algorithm metrics in AIM-VIS will be analyzed and performance described. The experimental results demonstrate the effectiveness of the proposed methodology in object and activity detection and exploitation for CBIR.

9473-10, Session 2

Video rate 3D registration of airborne video

David Bottisti, Lockheed Martin Missiles and Fire Control (United States); Suresh Subramaniam, The George Washington Univ. (United States)

Geo-registration of airborne image or video data provides a mapping of focal plane array pixels to inertial latitude and longitude coordinates. The airborne image is compared with a reference map using correlation methods in order to estimate an invertible projective transformation from pixel to inertial space. While registration to a two dimensional map is adequate for flat earth conditions, this can produce unacceptable errors in non-planar terrains. In this paper, we describe an alternative method whereby the geo-referenced database is augmented with altitude information in order to enable 3-dimensional rendering of the approximate area surrounding the subject image. We utilize OpenGL to assist in the 3-dimensional rendering and take advantage of several terrain and data compression algorithms to enable efficient storage and transmission of raster data. Our approach paves way for video rate 3D registration.

9473-11, Session 2

Incorporating structure from motion uncertainty into image-based pose estimation

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A method for generating and utilizing structure from motion (SfM) uncertainty estimates within image-based pose estimation is presented. The method is applied to a class of problems in which SfM algorithms are utilized to form a reference model of a particular ground area using imagery gathered during flight by a small unmanned aircraft. The model is then used to form pose estimates in near real-time from imagery gathered later. The resulting pose estimates can be utilized by any of the other onboard systems (e.g. as a replacement for GPS data). However, many of the consumers of pose estimates require an assessment of the pose accuracy. The method for generating the accuracy assessment is presented.

First, the uncertainty in the reference model is constructed. Sparse Bundle Adjustment (SBA) is utilized for model generation. While the high-level approach for generating a covariance matrix of the SBA parameters is straightforward, typical computing hardware is not able to support the required operations due to the scale of the optimization problem within SBA. Therefore, a series of sparse matrix operations is utilized to form an exact covariance matrix for only the parameters that are needed at a particular moment. Once the uncertainty in the model has been determined, it is used to augment Perspective-n-Point pose estimation algorithms to improve the pose accuracy and to estimate the resulting pose uncertainty.

The implementation of the described method is presented along with results including results gathered from flight test data.

9473-12, Session 2

Full motion video geopositioning algorithm integrated test bed

John T. Dolloff, Bryant M. Hottel, Peter J. Doucette, Aaron Braun, Henry J. Theiss, Adam Gurson, Integrity Applications, Inc. (United States)

In order to better understand the issues associated with Full Motion Video (FMV) geopositioning and to develop corresponding strategies and algorithms, an integrated test bed is required. It is used to evaluate the performance of various candidate algorithms associated with registration of the video frames and subsequent geopositioning using the registered frames. Major issues include reliable error propagation or predicted solution accuracy, optimal vs. suboptimal vs. divergent solutions, robust processing in the presence of poor or non-existent a priori estimates of sensor metadata, difficulty in the measurement of tie point between adjacent frames in the presence of noisy data and few discernable features, poor imaging geometry including small field-of-view and little vertical relief, and no control (points). Depending on the operational scenario, any combination of the above is possible and an FMV geopositioning system must be able to address them. The development and appropriate use of an integrated test bed is an essential early step. It must be integrated in that major processing modules are interconnected with appropriate data flows between them. It must be able to handle both simulated and real data and evaluate performance based on module-internal metrics as well as comparisons to simulated or real "ground truth'. Selection of the appropriate modules and algorithms must be both operator specifiable as well specifiable automatic. An FMV test bed has been developed and continues to be improved with the above characteristics. The paper describes its overall design as well key underlying algorithms. Performance of tested scenarios is also summarized.

9473-13, Session 2

Geostatistical modeling of uncertainty, simulation, and proposed applications in GIScience

Peter J. Doucette, John T. Dolloff, Integrity Applications, Inc. (United States)

Geostatistical modeling of spatial uncertainty has its roots in the mining, water and oil reservoir exploration communities, and has great potential for broader applications as proposed in this paper. This paper describes the underlying statistical models and their use in both the estimation of quantities of interest and the Monte-Carlo simulation of their uncertainty or errors, including their variance or expected magnitude and their spatial correlations or inter-relationships. These quantities can include 2D or 3D terrain locations, feature vertex locations, or any specified attributes whose statistical properties vary spatially. The simulation of spatial uncertainty or errors is a practical and powerful tool for understanding the effects of error propagation in complex systems. This paper describes various simulation techniques and trades-off their generality with complexity and speed. One technique recently proposed by the authors, Fast Sequential Simulation, has the ability to simulate millions of errors with specifiable variance and spatial correlations in a few seconds on a lap-top computer. This ability allows for the timely evaluation of resultant output errors or the performance of a "down-stream" module or application. It also allows for near-real time evaluation when such a simulation capability is built into the application itself.

9473-14, Session 3

GeoMesa: a distributed architecture for multi-source spatio-temporal fusion

Anthony Fox, Commonwealth Computer Research, Inc. (United States)

Recent advances in distributed databases and computing have transformed the landscape of spatio-temporal machine learning. This paper presents GeoMesa, a distributed spatio-temporal database built on top of Hadoop, Accumulo, and HBase and a suite of tools for analyzing vector and raster data. GeoMesa addresses the problem of indexing and distributing vector and raster spatio-temporal data across a cluster of compute and storage resources in a manner suitable for analytics. The indexing technique utilizes space filling curves to optimally map multi-dimensional data to the single lexicographic dimension dictated by the distributed database. This approach of linearizing the keyspace and distributing the index and data effectively optimizes query processing by parallelizing the data traversal while simultaneously reducing the number of false positives that have to be pruned. In contrast to traditional non-distributed RDBMS, GeoMesa is capable of scaling horizontally by adding more resources at runtime; the index rebalances across the additional resources. In the raster domain, GeoMesa leverages Accumulo's server-side iterators and aggregators to perform raster interpolation and associative map algebra operations in parallel at query time. The paper concludes by describing the application and deployment of GeoMesa in support of georegistration for draping FMV over terrain.

9473-15, Session 3

Addressing fundamental architectural challenges of an activity based intelligence and advanced analytics (ABIAA) system

Matthew F. Pellechia, Kevin C. Yager, Thomas A. Albert, Bernard V. Brower, Shiloh L. Dockstader, Exelis Inc. (United States)

The domain of Geospatial Intelligence Analysis is rapidly shifting toward a new paradigm to enable Activity Based Intelligence (ABI) and toward information-based Tipping and Queuing. System level requirements that describe an advanced ABIAA system translate into significant challenges in systems design, computing resources, data volumes, workflow efficiency, imaging algorithms and database science. In one example, ABI software systems will have advanced algorithms with logic to automatically flag activities that humans don't have time to find, and in places that humans would not have been looking, while maintaining geospatial data accuracy Approaching an ABIAA system in an architectural serial workflow (tasking, collection, processing, exploitation and dissemination) may produce short-term concept implementations, however, can present longer-term barriers in realizing the intent of the true ABIAA system. This paper provides an overview of an ABIAA system, with an assessment of the differentiation against legacy systems. ABIAA architectural considerations will be discussed, exploring the trades and issues between the hardware computing environment and advanced software processing components. Examples of several architectural components will be demonstrated and measured against requirements. This paper concludes with a recommended strategy and incremental approach to the research, development and delivery of an operational ABIAA system.

9473-16, Session 3

Technologies for on-the-move standoff explosive hazard detection

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The U.S. Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate have developed a flexible and modular testbed system by integrating vehicle mounted forward-looking EO-IR and down-looking airborne sensors along with an algorithm development framework built on

gstreamer to research, develop and evaluate on-the-move forward-looking explosive hazard detection capabilities.

The primary emphasis of the effort has been to develop a testbed system with a flexible and modular sensor integration architecture and unified processing and exploitation framework for algorithm development which allows easy integration and evaluation of new sensors, sensor subsystems and algorithms from different providers. The effort seeks to develop ground vehicle mounted stabilized multi-band sensors to detect in-road threats with adequate standoff and processing workstation and cueing algorithms and for automated and aided detection of buried IEDs and ambush indicators from ground and airborne standoff sensors.

The forward-looking explosive hazard detection system completed initial integration and implementation of the end-to-end system for on-the-move real-time aided inroad threat detection using forward looking EO/IR sensors. The system includes service based sensor integration architecture, Video Processing and Exploitation Framework (VPEF) based detection and a common user interface. The system demonstrated the capability to handoff threat cues detected by the vehicle mounted forward looking sensor to other confirmation and situational awareness sensors. The system is being used to collect target signatures in multiple environments to help improve detection performance with multi-sensor fusion algorithms.

The paper will present details of the sensor integration and algorithm development frameworks, broad performance results from on-going test and evaluations, and identification of the technology challenges for further development and performance improvements.

9473-17, Session 3

Semantically enabled image similarity search

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High spatial resolution satellite or aerially collected imagery offer an extensive, detailed, and instantaneous viewpoint of large geospatial extents. For an analyst to effectively search for a target in these images both the target signature and the imagery need to occupy the same data space. Depending on the acquisition modality, the methodology to both condition and process the data to execute any type of search functionality can be complex and requires either domain expertise or considerable training. To date, object-based feature extraction techniques, built on top of machine learning algorithms, have shown the most promise for accurate and robust image search. Despite these advances, searching for targets of interest in overhead imagery datastores remains computationally expensive and reliant on expertise.

Arguably, the simplest way to formulate a search request against imagery is through either language or example imagery. For example, find all the shipping containers in a given scene, or find all the areas of this image that contain content similar to a sample image of a shipping container. While image comparison via object-based feature extraction methods can be executed in the image domain, the ability to search for objects semantically with respect to their labels or geospatial context requires a semantic embedding model. Traditionally, semantic embedding models have been used to represent the individual words from a corpus of text as high-dimensional vectors in a space where semantically similar words are embedded near one another. Through these means, words of similar contextual meaning are represented by similar vectors, yielding a data space ideal for classification, clustering, and similarity search.

The methodology presented here demonstrates the capability to perform semantically enabled wide-area image search in a distributed processing environment. The approach enables an analyst to search a large datastore of overhead imagery from either a simple language query or example imagery. To facilitate the mapping between language and imagery, a unified embedding space was created by exploiting a geospatial network graph derived from GIS information and SIFT-like features derived from imagery. The geospatial context corpus was generated from the GIS-derived network graph and was then passed through a Word2Vec-based pipeline to produce vector representations for each word. The GIS data layer also contributed to large area segmentation and training data generation. The embedding model ultimately generated by this process is also able to be transferred and applied to areas of interest where detailed GIS or feature level information is unavailable. Additional advantages of this approach is the ability to disambiguate between similar labels and the capability to produce additional training sets on the fly that can be run as new classifiers. The tool leveraging this technology, Spookfish, is deployed on a computing cloud, backed by both Accumulo and GeoMesa, and is accessible by a user via a simple webapp to ensure scalability.

9473-18, Session 4

Effects of camera location on the reconstruction of 3D flare trajectory with two cameras

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Flares are used as valuable electronic warfare assets for the battle against infrared guided missiles. The trajectory of the flare is one of the most important factors that determine the effectiveness of the counter measure.

Reconstruction of the three dimensional (3D) position of a point, which is seen by multiple cameras, is a common problem. Camera placement, camera calibration, corresponding pixel determination in between the images of different cameras and also the triangulation algorithm affect the performance of 3D position estimation.

In this paper, we specifically investigate the effects of camera placement on the flare trajectory estimation performance by simulations. Firstly, 3D trajectory of a flare and also the aircraft, which dispenses the flare, are generated with simple motion models. Then, we place two virtual ideal pinhole camera models on different locations. Assuming the cameras are tracking the aircraft perfectly, the view vectors of the cameras are computed. Afterwards, using the view vector of each camera and also the 3D position of the flare, image plane coordinates of the flare on both cameras are computed using the field of view (FOV) values. To increase the fidelity of the simulation, we have used two sources of error. One is used to model the uncertainties in the determination of the camera view vectors, i.e. the orientations of the cameras are measured noisy. Second noise source is used to model the imperfections of the corresponding pixel determination of the flare in between the two cameras. Finally, 3D position of the flare is estimated using the corresponding pixel indices, view vector and also the FOV of the cameras by triangulation. All the processes mentioned so far are repeated for different relative camera placements so that the optimum estimation error performance is found for the given aircraft and flare trajectories.

9473-19, Session 4

Learning Based Roof Style Classification in 2D Satellite Images

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Accurately recognizing building roof style leads to a much more realistic 3D building modeling and rendering. In this paper, we propose a novel system for image based roof style classification using machine learning technique. Our system is capable of accurately recognizing four individual roof styles and a complex roof which is composed of multiple parts. We make several novel contributions in this paper. First, we propose an algorithm that segments a complex roof to parts which enable our system to recognize the entire roof based on recognition of each part. Second, to better characterize a roof image, we design a new feature extracted from a roof edge image. We demonstrate that this feature has much better performance compared to recognition results generated by Histogram of Oriented Gradient (HOG), Scale-invariant Feature Transform (SIFT) and Local Binary Patterns (LBP). Finally, to generate a classifier, we propose a learning scheme that trains the classifier using both synthetic and real roof images. Experiment results show that our classifier performs well on several test collections.

9473-20, Session 4

Context exploitation in intelligence, surveillance, and reconnaissance for detection and tracking algorithms

Jonathan D. Tucker, Lockheed Martin Corp. (United States); Robert Stanfill, Lockheed Martin Missiles and Fire Control (United States)

Intelligence, Surveillance, and Reconnaissance (ISR) missions involve complex analysis of sensor data that can benefit from the exploitation of geographically aligned context. In this paper we discuss our approach to utilizing geo-registered imagery and context for the purpose of aiding ISR detection and tracking applications. Specifically this includes rendering context masks on imagery, increasing the speed at which detection algorithms process data, providing a way to intelligently control detection density for given ground areas, identifying difficult traffic terrain, refining peak suppression for congested areas, reducing target center of mass location errors, and increasing track coverage and duration through track prediction error robustness.

9473-21, Session 4

Mosaicing with Poisson blending regularization for wide area motion imagery

V. B. Surya Prasath, Raphael Viguier, Kannappan Palaniappan, Univ. of Missouri-Columbia (United States); Gunasekaran Seetharaman, Air Force Research Lab. (United States)

We study mosaicing for wide area motion imagery (WAMI) data using poisson blending regularization. Exploitation of full motion video and WAMI data is crucial for change detection, target tracking, activity-based recognition and 3D reconstruction. Creating a mosaicing of WAMI data is challenging due to problems such as blurring, ghosting due to parallax and varying image exposures. In this work we review image alignment and panoramic mosaicing techniques for WAMI data and identify corresponding challenges for these existing methods. We describe mosaicing with Poisson blending based regularization which helps avoid blending of colors from different frames. Experimental results show that we obtain seamless mosaics from full motion videos without artifacts associated with existing approaches.

9473-22, Session 4

Real-time automated detection, tracking, classification, and geolocation of dismounts using EO and IR FMV

Justin Muncaster, Gaemus E. Collins, Jon Waltman, Toyon Research Corp. (United States)

The VideoPlus-Aware infrastructure security system is described. An evaluation the system was performed at the Y-12 National Security Complex and McGhee Tyson Air Base in partnership with the Toyon Research Corporation. The system is designed to enable autonomous video-based, moving target detection, tracking and classification. Additionally, the system has the ability to classify basic actions such as the breaching of or entry into a secure area.

Robust systems performing detection, tracking, and classification of targets at a distance have been elusive due to the immense computation required to obtain satisfactory performance. Toyon Research Corporation has developed algorithms that enable the real-time automated classification of humans in video that are as small as 25-pixels tall. This substantially improves the applicability of such systems by widening the permissible camera field-of-views and increasing the permissible ranges at which targets can be tracked and classified. Toyon's algorithms are able to do this with high detection rates and minimal false alarms.

The system is composed of real-time algorithms for stabilization, moving-target detection, stationary-target detection, target classification, target tracking, and target geo-location. The system requires minimal, one-time calibration and works on EO video streams as well as multiple IR bands. A subset of these algorithms, including the data-reduction and machine-learning techniques that enabled real-time execution and classification of very-small targets will be discussed.

An evaluation occurred in operational environments on the Department of Energy Oak Ridge Reservation and the McGhee Tyson Air Base. The system was tested at varying ranges from 20 to 700 meters, during day and night operation and using both thermal and visual cameras. Test subjects included canines and humans walking and breaching a secure area. Testing included single and multiple human and canine targets in a variety of profiles and paths. The testing environment included tree lines, short and long mowed grass fields, asphalt paved roads, gravel beds, fences, power lines and additional items of interest/movement.

The evaluation quantified the system's abilities to detect, classify, track humans and transmit the information to external applications. The evaluation provided 811 separate data points gathered over a period of four days with an overall probability of sensing of 99.9%. The probability of detection was 86.2% and the percentage of correct action classification was 82%. The data provided a False Alarm Rate of 0 per hour and Nuisance Alarm Rate of 0.72 per hour.

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9474-1, Session 1

Comparison of the performance of some multiple target tracking algorithms with experimental airborne radar data

Bhashyam Balaji, Defence Research and Development Canada (Canada); Kai Wang, MacDonald, Dettwiler and Associates Ltd. (Canada); Anthony Damini, Defence Research and Development Canada (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 multiple 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 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. A more modern solution is the Gaussian mixture probabilistic hypothesis density (GM-PHD) filter.

In this paper, we will compare the performance of several trackers. In particular, we will consider the independent PDA (where the initiated tracks are evolved independently), the joint probabilistic data association (JPDA) algorithm and variants that include target existence probability for each track ---the integrated PDA (IPDA) and joint integrated PDA (JIPDA) --- and the GM-PHD filter. We compare the performance of these algorithms with simulated as well as real data.

9474-2, Session 1

Aspects of detection and tracking of surface targets from an airborne EO/IR sensor

Bhashyam Balaji, Zahir Daya, Rajiv Sithiravel, Defence Research and Development Canada (Canada); Thiagalingam Kirubarajan, McMaster University (Canada)

Commercial off-the-shelf EO/IR sensors are often a part of a multi-sensor suite of sensors on military as well as civilian aircraft. The camera system can be used to scan large swaths of area (perhaps being cued by a radar or ESM sensor), and detect potential targets of interest. It is of interest to detect and track and identify potential targets, and potentially fuse the outputs with those of other sensors.

From a detection and tracking perspective, the problem is to detect potential targets in a sequence of frame in a bearing-elevation grid and ascertain kinematic parameters. In contrast to other sensors, such as radar, extensive work on tracking from airborne EO/IR sensor has not be published extensively.

In this paper, the filtering model for tracking surface targets is formulated. We begin by first using some standard single-frame and multiple frame moving target detection and estimation algorithms. The centroids, in the bearing-elevation grid are then used as input to tracking filter. The nonlinear filtering problem is then formulated as the problem with state model described by jump Markov processes and the measurement model described by bearing and elevation measurements. The performance of standard filtering algorithms, such as the variable state interacting multiple model with extended Kalman filter and the unscented Kalman filter, is assessed in simulated and real data. The performance of the tracking filter is compared to the posterior Cramer-Rao lower bound.

The EO/IR sensor comprises of a suite of sensors, such as a narrow and wide field of view EO sensor and and IR sensor. Thus, there is a need for a capability to fuse the outputs from the individual sensors. The benefits of the kinematic fusion is also investigated.

9474-3, Session 1

Computationally efficient angles-only tracking with particle flow filters

Russell Costa, Thomas A. Wettergren, Naval Undersea Warfare Ctr. (United States)

We examine a problem of tracking a four-state target using only angles-only information. The conventional state-of-the-art for such a tracking problem is to use a particle filter, as they provide a robust solution technique for nonlinear non-Gaussian filtering. However, the use of particle filters suffers from the curse of dimensionality as the problem dimensionality grows. Recently, Daum and Huang have developed a related approach that avoids the dimensionality restrictions of particle filters. Their new method, called a particle flow filter, is a deterministic alternative that replaces the sampling and re-sampling steps of a particle filter with a homotopy filter leading to a partial differential equation across the states. We examine the use of these new filters on a problem of angles-only tracking, in which target state is recursively estimated on a dynamic set of angles-only measurements of relative target position. We apply the exact particle flow method, in which we assume a Gaussian prior and likelihood function of the unknown target states. We compare the performance and computational burden for the particle flow approach with that obtained from a standard particle filter. The example problems we look at assume a simple target motion problem with angles-only measurements of target location that are corrupted by additive Gaussian noise of unknown variance. While the historical solution of such problems is to apply the extended Kalman filter, the current state-of-the-art is the particle filter. In our comparisons of the performance of the newer particle flow filter to both the extended Kalman filter and the regular particle filter, we show both the computational benefits and the potential implementation pitfalls. We conclude with some suggestions on future investigations for improving the implementation of these new filters in angles-only tracking.

9474-4, Session 1

Multisensor fusion for 3D target tracking using track-before-detect particle filter

Nima Moshtagh, Paul M. Romberg, Moses W. Chan, Lockheed Martin Space Systems Co. (United States)

We have developed a novel fusion mechanism to track and estimate the three-dimensional trajectory of a moving target using images collected by multiple EO/IR sensors. The proposed fusion engine avoids the explicit target detection stage prior to fusion. Instead, a centralized particle filter implements multiple track-before-detect filters on each individual image collection. In the central processing center the images are collected and registered given the known pointing information of the sensors, and using a perspective projection of the particles onto the images, intensity values from multiple sensors are directly used as measurements. The particles states (and weights) are updated using the joint likelihood computed from all the collections onto which the particles are projected. The 3D trajectory of target ("system track") is then generated from the states of the particles.

The performance of this centralized fusion method is compared with that of a track-to-track fusion (T2TF) algorithm. The T2TF algorithm is considered a distributed fusion mechanism because the 2D sensor tracks are separately generated and transmitted to a fusion center, where they are converted into line-of-sight (LOS) measurements. The LOS measurements are then registered in the geo-coordinates and fused to reconstruct the 3D system track. A realistic synthetic scenario with a dim target is used for performance comparison. The advantages and drawbacks of each method are discussed.

9474-5, Session 1

Target visibility for multiple maneuvering target tracking

Madeleine G. Sabordo, Elias Aboutanios, The Univ. of New South Wales (Australia)

We present a recursion of the probability of target visibility and its applications to analysis of track life and termination in the context of Global Nearest Neighbour (GNN) approach and Probability Hypothesis Density (PHD) filter. In the presence of uncertainties brought about by clutter; decisions to retain a track, terminate it or initialise a new track are based on probability, rather than on distance criterion or estimation error. The visibility concept is introduced into a conventional data-association-oriented multi-target tracker, the GNN; and a random finite set based-tracker, the PHD filter, to take into account instances when targets become invisible or occluded by obstacles. The presence of clutter in the signal environment poses challenges to researchers in resolving the data association problem. Clutter consists of noise and false alarms which may present themselves in the form of moving and stationary objects as well as electronic countermeasures like jammers, chaffs, flares and decoys (to name a few). We assume that target detection is independent of clutter detection and clutter returns received at different sampling times are independent. Associating measurements to targets forms the bulk of computational requirements in many conventional multi-target tracking systems. The target visibility concept takes into account these association probabilities and measurement likelihoods to predict and update the probability of visibility. An elegant alternative to the data association tracking approach is the Random Finite Set (RFS) paradigm, popularised by Mahler. The PHD filter is an example of this paradigm. It propagates the first-order statistical moment of the RFS of states in time. The visibility concept takes into account this intensity moment in predicting and updating the probability of visibility. We assume that not all tracks correspond to a valid target as moving objects may move out of the surveillance region, aircraft land or targets may be occluded by physical barriers or electronic warfare systems. We use the GNN and PHD trackers to estimate the states of multiple manoeuvring targets. The Dynamic Error Spectrum is then used to assess the performance of the trackers with and without probability of visibility incorporated. Simulation results show that the performance of trackers with visibility concept incorporated is significantly enhanced.

9474-6, Session 2

Robust approach for space-based sensor bias estimation in the presence of data association uncertainty

Djedjiga Belfadel, Richard Osborne, Yaakov Bar-Shalom, Univ. of Connecticut (United States)

In this paper, a robust approach to bias estimation in the presence of measurement association uncertainty using common targets of opportunity, is developed. Data association is carried out before the estimation of sensor angle measurement biases. Consequently, the quality of data association is critical to the overall tracking performance. Data association becomes especially challenging if the sensors are passive. Mathematically, the problem can be formulated as a multidimensional assignment problem (MDA) where the objective is to maximize the likelihood that the associations measurements correspond to common targets. Applying gating techniques reduces significantly the size of this problem. First the k-best (ranked) solutions, based on the associated likelihoods, are determined using an exhaustive search algorithm, then, an acceptance test (which takes into account the estimation of the 3D Cartesian locations of the targets of opportunity and the angle measurement biases of the sensors) is applied to each of k-best solutions in order to discriminate the optimal (correct) solution.

We demonstrate the merits of this robust approach by applying it to a simulated tracking system, which consists of two or more satellites tracking a ballistic target. We assume the sensors are synchronized, their locations are known, and we estimate their orientation biases.

9474-7, Session 2

Square-root formulation of the SVSF with target tracking applications

Stephen A. Gadsden, Univ. of Maryland, Baltimore County (United States)

The smooth variable structure filter (SVSF) is a state and parameter estimation strategy based on sliding mode concepts. It has seen significant development and research activity in recent years. In an effort to improve upon the numerical stability of the SVSF, a square root formulation is derived. The square root SVSF is based on Cholesky factorization and U-D decomposition. The proposed formulation is computationally more efficient and reduces the risks of failure due to numerical instability. The new strategy is applied on target tracking scenarios for the purposes of state estimation. The results are compared with the popular Kalman filter.

9474-8, Session 2

Minimum-variance smoother based on the SVSF estimation strategy

Stephen A. Gadsden, Univ. of Maryland, Baltimore County (United States); Thia Kirubarajan, McMaster Univ. (Canada)

The smooth variable structure filter (SVSF) has seen significant development and research activity in recent years. It is based on sliding mode concepts, which utilizes a switching gain that brings an inherent amount of stability to the estimation process. In this paper, the SVSF is reformulated to present a minimum-variance smoother based on the SVSF gain. The proposed method is applied on a variety of target tracking scenarios, and the results are compared with other popular smoothers.

9474-9, Session 2

Orchestrated management of heterogeneous sensors incorporating feedback from intelligence assets

Yugandhar Sarkale, Edwin K. P. Chong, Colorado State Univ. (United States)

We develop a method for autonomous management of multiple heterogeneous sensors for a multiple target tracking problem. We adopt a non-myopic (long-term) method known as partially observable Markov decision process (POMDP) to formulate the problem. POMDP incorporates long-term decision making, effective for managing limited resources (sensors), and accounts for uncertainties arising from noisy measurements. The main contribution of the paper is incorporation of feedback received from intelligence assets (humans) on priorities assigned to specific targets into the decision making process. Information received from assets is modeled as a penalty on the cost function. The resulting constrained optimization problem is solved using an augmented Lagrangian method. The cost function is the mean squared error between the tracks and target states. The suite of sensors consists of ground-based platforms and sensors on board multiple unmanned aerial vehicles (UAVs). Each sensor collects measurements of the locations of multiple targets and each sensor has one or more controllable aspects, e.g., on/off activation for ground-based sensors, location for sensors mounted on UAVs, and sensing direction for sensors with limited field-of-view. Information obtained from sensors and assets is fused together centrally for guiding the UAVs to track these targets. We impose dynamic constraints on the motion of the UAVs and there is a spatially varying error associated with the measurements of the sensors. POMDPs are intractable to solve exactly. We use an approximation technique known as nominal belief state optimization (NBO), which is known to be computationally efficient and well suited for target tracking applications.

9474-10, Session 2

Probabilistic track-to-track association

Tim Zajic, Raytheon Co. (United States)

Track-to-track association remains a challenging problem and is a critical ingredient when performing fusion in the presence of multiple targets. Successful association depends both on an appropriate model for the problem setting at hand as well as a tractable algorithm for the model given the available computing resources. In this work we first provide a discussion of the track-to-track association problem and a brief review of classical and recent approaches to the problem, as well as some recent works in the related area of data-to-track association. A new model is then put forth for performing probabilistic track-to-track association, in particular when attribute data is available which is to be fused. The model is tailored to the setting in which the track data is dense enough to warrant foregoing hard association and is developed with the requirements of computational time requirements in mind. The results of numerical experiments illustrate the performance of the approach.

9474-11, Session 3

CPHD filters with unknown quadratic clutter generators

Ronald P. S. Mahler, Consultant (United States)

: Previous research has produced CPHD filters that can detect and track multiple targets in unknown, dynamically changing clutter. The first such filters employed Poisson clutter generators and, as a result, were combinatorially complex. Recent research has shown that replacing the Poisson clutter generators with Bernoulli clutter generators results in computationally tractable CPHD filters. However, Bernoulli clutter generators are insufficiently complex to model real-world clutter with high accuracy because they are statistically first-degree. This paper addresses the derivation and implementation of CPHD filters when first-degree Bernoulli clutter generators are replaced by second-degree quadratic clutter generators. These filters are combinatorially second-order, but are more easily approximated and can be implemented in exact closed form using beta-Gaussian mixture (BGM) or Dirichlet-Gaussian mixture (DGM) techniques.

9474-12, Session 3

On multitarget pairwise-Markov models

Ronald P. S. Mahler, Consultant (United States)

Both single- and multi-target tracking are typically based on strong independence assumptions in regard to both the target states and sensor measurements. The motion(s) of the target(s) at the current time are assumed to independent of all but the immediately previous motion(s) of the target(s)—the Markov assumption. Likewise, current sensor measurement(s) are assumed to be independent of all but the current target state(s). Stated more formally, the theoretical basis of both single- and multi-target tracking is the hidden Markov chain (HMC) model. That is, the target process is a Markov chain that is indirectly observed via an independent observation process. It is desirable to relax the strong independence assumptions associated with HMC models. One approach that has been proposed for single targets is the pairwise Markov chain (PMC) model, in which the target state and the measurement jointly form a Markov chain. The HMC model can be directly generalized to multitarget problems, but the resulting tracking filters are computationally intractable. This paper investigates the possibility of developing PHD/CPHD filter approximations of multitarget HMC filters.

9474-13, Session 3

Distributed fusion of multitarget densities and consensus PHD filters

Giorgio Battistelli, Luigi Chisci, Claudio Fantacci, Univ. degli Studi di Firenze (Italy); Alfonso Farina, SELEX ES S.p.A. (Italy); Ronald P. S. Mahler, Consultant (United States)

Multi-target tracking is of great practical relevance for military situation awareness. Recent advances in wireless sensor technology have opened up the possibility to develop efficient surveillance systems consisting of the radio interconnection of multiple devices with built-in sensing, communication and processing capabilities. For effective exploitation of this emerging technology it is, however, fundamental to redesign the architecture and algorithms of multi-target trackers taking into account that: (1) any individual node has limited sensing capabilities; (2) processing must be carried out in a distributed fashion with no coordination of a fusion center; (3) each node is unaware of the correlations between its own information and the incoming information from other nodes. The primary goal of this paper is to present a theoretical approach to the distributed fusion of multi-target densities based on the information-theoretic concept of Kullback-Leibler average as well as on the use of consensus employed for performing a global fusion of multi-target densities over the whole network by iterating regional fusions over subnetworks of neighboring nodes. In particular, it is shown how the proposed distributed fusion is inherently immune to double-counting of data. When the information available in each node can be expressed as a (possibly cardinalized) Probability Hypothesis Density (PHD), application of the proposed distributed fusion rule leads to a consensus PHD filter which can be conveniently implemented by resorting either to particle or Gaussian mixture representations. In particular, the Gaussian mixture consensus PHD filter is characterized by a parsimonious representation of the multi-target information, and hence is well-suited to being applied also when the individual nodes have limited computational capabilities and must possibly limit data transmission so as to reduce energy consumption and prolong network lifetime.

9474-14, Session 3

A distributed general multisensor cardinalized probability hypothesis density (CPHD) filter for sensor networks

Syamantak Datta Gupta, Santosh Nannuru, Mark Coates, Michael Rabbat, McGill Univ. (Canada)

The cardinalized probability hypothesis density (CPHD) filter has proven to be an extremely effective method for tracking multiple targets based on measurements recorded by a single sensor; computationally tractable algorithms based on Gaussian mixtures or particle filters have been applied successfully in multiple practical settings. There has been less work extending the filter to the multi-sensor and sensor network settings. For the case of centralized computation, two major approaches have been proposed: the heuristic iterated-corrector approximation and the multi-sensor product approximation. If computation is distributed throughout the network, most existing algorithms involve individual sensor nodes performing local CPHD filter updates using only the measurements recorded by that sensor. The nodes then exchange data to fuse their local intensity functions and cardinality distributions. Recently, we derived update equations for the general multi-sensor CPHD filter and proposed a computationally tractable implementation. The algorithm involves a greedy search procedure that identifies subsets of measurements that have substantial likelihood of being derived from the same target. In its current form, the implementation relies on a fusion centre having access to the measurements recorded by all sensors. In this paper, we describe how the algorithmic computation can be distributed throughout a sensor network to avoid the exchange of raw measurements. We report the results of simulations that examine the trade-off between accuracy and communication overhead for the proposed algorithm and compare it with existing CPHD fusion techniques.

9474-15, Session 3

Integrate knowledge acquisition with target recognition through closed-loop ATR

Ssu-Hsin Yu, Pat McLaughlin, Aleksandar Zatezalo, Scientific Systems Co., Inc. (United States); Kai-yuh Hsiao, Jovan Boskovic, Scientific Systems Co Inc (United States)

ATR algorithm performance is highly dependent on the sensing conditions (e.g. orientation, distance, sensor type) under which the input data is collected. Open-loop fly-bys often produce poor results due to less than ideal measurement conditions. Instead of improving target classification performance only through better ATR algorithms, our approach, closed-loop ATR (CL-ATR), focuses on improving the quality of information inputs to ATR algorithms by optimizing motion, sensor settings and team collaboration to dramatically improve ATR accuracy. By managing the data collection guided by predicted ATR performance gain through, we increase the information content of the data and thus dramatically improve ATR performance with existing ATR algorithms.

CL-ATR begins with ATR utility function, which represents the performance sensitivity of ATR-produced classification labels as a function of parameters that correlate to vehicle/sensor states. This utility function is developed off-line and is often available from the original ATR study, for example, as a confusion matrix, or it can be derived through simulation without direct access to the inner working of the ATR algorithm. The utility function is inserted into our CL-ATR framework to autonomously control the vehicle/sensor. Because we only require the utility function on-board, we can activate any ATR algorithm onto a UAV platform.

Our approach uses ATR information gain as the primary driver for UAV actions. We apply Bayesian state posterior updates to fuse prior and on-line information. The utilities to measure effectiveness of an action as well as what actions are feasible may vary from behavior to behavior depending on its objective, but the decision process to determine the best course of actions is the same. We use Partially Observable Markov Decision Process (POMDP) as the decision mechanism. To reduce computational load, we apply the finite horizon Model Predictive Control (MPC) algorithm to implement POMDP. Compared with open-loop systems, this produces a dramatic improvement in ATR performance.

9474-18, Session 3

Random Finite Set Multi-Target Trackers: Stochastic Geometry for Space Situational Awareness

Ba-Ngu B. Vo, Ba-Tuong Vo, Curtin Univ. (Australia)

This paper introduces a systems theoretic framework for SSA using stochastic geometry. Random finite set is the most natural and elegant model for the collection of orbital space objects, since it captures the uncertainty in the number of objects, their states and interactions such as repulsion (from evasive manoeuvres) and spawning (from collisions that generate more objects). Moreover, Stochastic geometric constructs such as intensity function, void probabilities, Palm distribution etc. are the ideal tools for many key SSA tasks such as conjunction analysis, collision warning, evasive manoeuvre planning, etc. This formulation encapsulates the uncertainty in the collection of orbital objects, the orbital space environment, and the dynamic network of sensors as a whole, and provides the tools for analysis of such complex system.

9474-19, Session 4

Proof that particle flow corresponds to Bayes' rule: necessary and sufficient conditions

Frederick E. Daum, Raytheon Co. (United States)

We prove that particle flow corresponds to Bayes' rule, subject to certain regularity conditions (nowhere vanishing and smooth probability densities) using a clever method of Moser & Dacorogna. It is easy to show that particle flow is a necessary condition for Bayes' rule, but the proof that it is sufficient is substantially more complex, and it requires an additional condition, namely that the Jacobian of the flow is non-singular. Our theory can be applied to essentially any decision or estimation problem, such as: sensor fusion, tracking, Bayesian decisions and learning, communications, predicting the stock market and the weather.

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, as well as transport problems with smooth nowhere vanishing densities. 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. We solve our PDE analytically as a formula, rather than using numerical methods, in order to reduce computational complexity. We show 26 distinct methods for solving this PDE. We explain why engineers like particle filters, but we also show that particle filters generally suffer from the curse of dimensionality. We explain the root cause of particle degeneracy with a simple cartoon, and we show how to solve it using particle flow. Recent results include a new algorithm for particle flow that uses the same formula as maximum likelihood estimation but for each particle rather than only for the point estimate of the state; this formula uses the observed Fisher information matrix and the score, both well known in classical statistics. The resulting ODE for the flow can be very stiff, but we show several methods to mitigate stiffness at a small cost in computational complexity. Finally, we compare particle flow with standard transport algorithms. This talk is for normal engineers who do not have nonlinear filters for breakfast.

9474-20, Session 4

A baker's dozen of new particle flows for nonlinear filters, Bayesian decisions and transport

Frederick E. Daum, Jim Huang, Raytheon Co. (United States)

We have invented eight new particle flow algorithms to compute Bayes' rule for nonlinear filters, Bayesian decision & learning as well as transport problems: (1) Moser's coupling applied to particle flow for Bayes' rule; (2) Gibbs sampler like flow; (3) non-singular Jacobian flow; (4) suboptimal Monge-Kantorovich flow; (5) exponential family flow with non-zero diffusion; (6) Gaussian flow with non-zero diffusion; (7) maximum entropy flow; and (8) maximum relative entropy flow. 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, as well as transport problems with smooth nowhere vanishing densities. 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. We solve our PDE analytically as a formula, rather than using numerical methods, in order to reduce computational complexity. We show 34 distinct methods for solving this PDE. We explain why engineers like particle filters, but we also show that particle filters generally suffer from the curse of dimensionality. We explain the root cause of particle degeneracy with a simple cartoon, and we show how to solve it using particle flow. Recent results include a new algorithm for particle flow that uses the same formula as maximum likelihood estimation but for each particle rather than only for the point estimate of the state; this formula uses the observed Fisher information matrix and the score, both well known in classical statistics. The resulting ODE for the flow can be very stiff, but we show several methods to mitigate stiffness at a small cost in computational complexity. Finally, we compare particle flow with standard transport algorithms. This talk is for normal engineers who do not have nonlinear filters for breakfast.

9474-21, Session 5

Feynman path integral and Monte Carlo methods for nonlinear filtering

Bhashyam Balaji, Defence Research and Development Canada (Canada)

The continuous-time nonlinear filtering problems can be formulated and solved in terms of a Feynman path integral(FPI). The FPI formulation has several advantages over other methods. In particular, it can be shown that the FPI in nonlinear filtering is closely related mathematically to the FPI in quantum mechanics, even though conceptually they are far from similar. Furthermore, the FPI has had a deep impact on modern theoretical physics, including quantum field theory and string theory and led to several deep conjectures in many areas of pure mathematics.

However, except for certain special cases, the FPI cannot be solved exactly. Thus, one needs to resort to numerical approximation methods. The FPI is particularly suitable for solution via numerical methods. In fact, in quantum field theory, the numerical implementation of the FPI has led to substantial progress in calculating quantities of interest that are otherwise incalculable, such as masses of composite particles, from the underlying fundamental quantum field theory of strong interactions, the field of lattice quantum chromodynamics (QCD).

Monte-Carlo methods form the basis for solving FPIs numerically. However, a naive implementation is highly inefficient. An interesting fact is that considerable progress in lattice QCD has been made by using effective actions that has much improved numerical properties, in particular a much faster convergence via improved discretizations.

The applicability of some of the techniques developed in the quantum field theoretical context is investigated. Since there is a close relationship between nonlinear filtering and quantum mechanics, many techniques are potentially useful in filtering theory. However, there are some significant differences in the types of quantities that are of interest in quantum mechanics and nonlinear filtering. The ideas and methods are illustrated via some numerical examples.

9474-22, Session 5

Feature-aided multiple hypothesis tracking using topological and statistical behavior classifiers

David M. Rouse, Johns Hopkins Univ Applied Physics Lab. (United States); Adam S. Watkins, Jonathan T. DeSena, Jesse C. Clarke, David W. Porter, Jeffrey Gilbert, Johns Hopkins Univ. Applied Physics Lab., LLC (United States); Paul Bendich, Nathaniel Strawn, Elizabeth Munch, John Harer, Duke Univ. (United States); Peter Chin, Draper Lab. (United States); Andrew J. Newman, Johns Hopkins Univ. Applied Physics Lab., LLC (United States)

This paper introduces a unified theory for target tracking using Multiple Hypothesis Tracking, Topological Data Analysis, and machine learning. The innovations of the approach are: using robust topological features to encode target behavior information; fitting statistical models to distributions over these topological features; and exploiting target type classification likelihoods derived from topological features within the tracker's hypothesis scoring procedure. The approach is tested and demonstrated on synthetic vehicular data generated by the Simulation of Urban Mobility package. Simulation results show that persistence, combined with learning, can provide an effective tool to measure and exploit target activity for improved image-based tracking.

9474-23, Session 5

OCULUS Sea track fusion service

Stylianos C. Panagiotou, Constantinos Rizogiannis, Stavros Katsoulis, Vassilis Lampropoulos, Sotirios Kanellopoulos, Stelios C. A. Thomopoulos, National Ctr. for Scientific Research Demokritos (Greece)

Oculus Sea is a complete solution regarding maritime surveillance and communications at Local as well as Central Command & Control level which was tested under real scenarios in the context of the PERSEUS-FP7-SEC-2010-1 EU research project. Oculus Sea includes a robust and independent track fusion service whose main functions include:

1) Interaction with the user to suggest the fusion of 2 or more Tracks, confirm Target ID and Target Metadata creation for the fused Track, and

suggest de-association of 2 Tracks (earlier fused).

2) Fusion of same target tracks arriving simultaneously from multiple radar sensors featuring Track Association (metrics that measure if tracks from different sensors can be fused), Track Fusion (combine associated tracks to produce the most accurate track), and Multiple tracking filters and fusion algorithms.

3) Unique ID Track Generator for each fused track

4) Track Dissemination Service.

Oculus Sea track fusion service adopts a system architecture where each sensor is associated with an estimator/tracker that obtains an estimate of the state vector and its respective error covariance. For the tracker, either a Kalman filter or a Particle filter algorithm can be selected depending on the kinematic model and the noise processes distribution. Finally, at the fusion center, association and track state estimation fusion are carried out.

The expected benefits of this system include Multisensor information fusion, enhanced spatial resolution, and improved target detection.

9474-24, Session 5

OCULUS Sea: integrated maritime surveillance platform

Sotirios Kanellopoulos, Stavros Katsoulis, Dionysis Motos, Vassilis Lampropoulos, Christos Margonis, Kostantinos Dimitros, Stelios C. A. Thomopoulos, National Ctr. for Scientific Research Demokritos (Greece)

OCULUS Sea Platform is a complete solution for Maritime Surveillance. It picks-up on the EUROSUR guidelines and CISE vision architecture to offer a “distributed” platform of National/ Regional/ Local Command & Control Centers (CCCs) that is “centrally governed”. “Distributed” (or “loosely coupled”) as CCCs are located separately – far from each other, share their Situational Pictures via a Message Oriented Middleware but preserve their Administrational and Operational capabilities. Practically this means that in the unlike event that the network communication with upper or neighboring CCCs fails, the local Situation Picture is not shared but all other operational capabilities work seamlessly. We say “centrally governed” as there exists an OCULUS central governance mechanism that: registers, authenticates, authorizes and monitors Regional & Local CCCs plus imposes dissemination rules to assure “Situational Awareness” meaning that Situation Pictures are seamlessly “shared” along the platform.

OCULUS Sea Platform offers “ingestion” and “fusion” services for vessels tracks. The “ingestion” service is compatible with most off-the-shelf surveillance track sensors (AIS- radar) plus major standardized track formats: NMEA, I-VEF, ASTERIX, other. On the other hand the track “fusion” service associates ingested tracks of the same vessel but from different sensors, and produces fused tracks in terms of geometry and vessel metadata.

OCULUS sea platform offers operators a powerful UI with a set of decision support services that assist them to perform accurately and on-time the appropriate operation flows depending on the incident.

9474-25, Session 5

A technique for sensors fusion with limited number of common measures

Carlo Quaranta, Giorgio Balzarotti, SELEX ES S.p.A. (Italy)

An algorithm is proposed here that overcomes the problem of the not exhaustive number of common measures from sensors of different type. As a matter of fact, in the presence of a suite of heterogeneous sensors the data fusion process has to deal with the problem of measuring different types of quantities, the latter mostly not comparable. The analysis of the mathematical model is carried out considering a data fusion system between Radar and IRST (Infrared Search and Track) where the measurement of the range is did by Radar only. In particular, in order to check robustness of the algorithm and its ability in the track-to-track association process, it is also considered the extreme case of fusion between IRST and two-dimensional Radar where there is only one common measure. Simulation results, demonstrating the effectiveness of the algorithm as regards the fusion process tracking and correctness of association between tracks from different sensors, are then provided.

The paper describes an extension of the data fusion algorithm described in a previous work published by OE (“Technique for radar and infrared search and track data fusion”, 2013)

The paper will be structured trough the following topics/indexes:

General definition of the Context for Data Fusion of two tactical airborne sensors

Detailed description of the measures available from IRST and from RADAR

Minimum set of data suitable for data fusion.

Optimum set of data for data fusion

Algorithm description and simulations

Read across the results

Note: the request for company’s clearance to publication is in progress

9474-26, Session 6

Grid Occupancy Estimation for Environment Perception Based on Belief Functions and PCR6

Julien Moras, Jean Dezert, Benjamin Pannetier, ONERA (France)

In this contribution, we propose to improve the grid map occupancy estimation method developed so far based on belief function modeling and the classical Dempster’s rule of combination. Grid map offers a useful representation of the perceived world for mobile robotics navigation. It will play a major role for the security (obstacle avoidance) of next generations of terrestrial vehicles, as well as for future autonomous navigation systems. In a grid map, the occupancy of each cell representing a small piece of the surrounding area of the vehicle must be estimated at first from sensors measurements (typically lidar, or laser), and then it must also be classified into different classes in order to get a complete and precise perception of the dynamic environment where the vehicle moves. So far, the estimation and the grid map updating have been done using fusion techniques based on the probabilistic framework, or on the classical belief function framework thanks to an inverse model of the sensors. Mainly because the latter offers an interesting management of uncertainties when the quality of available information is low, and when the sources of information appear as conflicting. To improve the performances of the grid map estimation, we propose in this paper to replace Dempster’s rule of combination by the PCR6 rule (Proportional Conflict Redistribution rule #6) proposed in DSmT (Dezert-Smarandache) Theory. As an illustrating scenario, we consider a car moving in an urban zone and we compare our new realistic simulation results (based on a 4-layers lidar sensor) with those obtained by the probabilistic and the classical belief-based approaches.

9474-27, Session 6

Issues and challenges of information fusion in contested environments panel

Erik Blasch, Air Force Research Lab. (United States); Ivan Kadar, Interlink Systems Sciences, Inc. (United States); Chee-Yee Chong, Independent Consultant (United States); Eric K. Jones, Systems & Technology Research (United States); Laurie H. Fenstermacher, Air Force Research Lab. (United States); John D. Gorman, Defense Advanced Research Projects Agency (United States); Georgiy M.

Levchuk, Aptima, Inc. (United States); Jorge E. Tierno, Barnstorm Research Corp. (United States)

With the plethora of information, there are many aspects to contested environments such as the protection of information, network privacy, and restricted observational and entry access. In this paper, we review and contrast the perspectives of challenges and opportunities for future developments in contested environments. The ability to operate in a contested environment would aid societal operations for highly congested areas with limited bandwidth such as transportation, the lack of communication and observations after a natural disaster, or planning for situations in which freedom of movement is restricted. Different perspectives were presented, but common themes included communications, control, social networks, information fusion for applications in cyber, surveillance, command and control, as well as situation awareness. The paper serves as a summary and organization of the panel discussion as towards future concerns for research needs in contested environments.

9474-28, Session 6

Multi-intelligence critical rating assessment of fusion techniques (MiCRAFT)

Erik Blasch, Air Force Research Lab. (United States)

Assessment of multi-intelligence fusion techniques includes reliability of algorithm performance, quality of results against mission needs, and usability in a work-domain context. Situation awareness (SAW) brings together low-level information fusion (tracking and identification), high-level information fusion (threat and scenario-based assessment), and Level 5 User refinement. To measure SAW, we utilize the SAGAT (Situational Awareness Global Assessment Technique) technique for a multi-Intelligence assessment that focuses on the advantages of MIF against single INT. The analysis includes SAGAT probes, SART (Situational Awareness Rating Technique) questionnaire, NASA TLX (Task Load Index), CDM (Critical Decision Method) with a focus on timeliness, accuracy, confidence, workload (cost), and attention (throughput). A key component of user analysis includes correlation, association, and summarization of data, so we also have measures of aesthetics of product quality. Notional results highlight the use of the MiCRAFT for verification and validation of multi-intelligence tools.

9474-29, Session 6

Data fusion, association, and retrieval in open-source multimedia

Georgiy M. Levchuk, Aptima, Inc. (United States)

The U.S. intelligence has an increasing need to fuse available data from National assets with existing open-source intelligence (OSINT) from local news, blogs, and social networks. The OSINT sources often contain both text and imagery that may be complementary, redundant, ambiguous, and intentionally deceptive. To understand the situation, the intelligence analysts must combine multiple sources and connect the events in time. During this process, it is critical to identify and discard misinformation while avoiding double-counting the redundant reports. To reconstruct the full state of the situation and track its evolution in time, the analysts must connect the events and entity mentions across time and multiple sources.

To understand the challenges association with OSINT exploitation, we analyzed the situation unfolding around downing of the Malaysian passenger airplane MH17 over Eastern Ukraine. This investigation, which did not come through traditional media or statements from intelligence agencies, was conducted mostly by crowd sourcing and journalists combining evidence from multiple non-traditional sources, including Twitter, Facebook, and Ukrainian and Russian social media platforms . All reports of value regarding MH17 contained the imagery and often video data critical in supporting the stated claims. The participants in different investigations had to go over significant amounts of ambiguous evidence, perform complicated geolocation tasks, and connect the event mentions across multiple sources. The reconstruction of the overall situation was complicated by presence of myriads of reports, many of which contained false statements and geolocation claims. This type of situation is similar to investigations that U.S. intelligence analysts may need to perform to discover the movements and activities of particular adversarial groups, including possession and use of mobile missile systems such as SA11 ground-to-air system (BUK) suspected in downing MH17. For many situations, the data from U.S. National assets may be available and could be combined with open-source data.

When combining multi-source data, it is critical to identify the claims from factual content. While many media sources have complementary information contained in text and imagery, oftentimes the images are stock photos, or photos taken from different locations and times, or the text in the sources misrepresents the context in the pictures. The analysis of Russian government controlled media revealed wide-spread misinformation, including information manipulation, misuse of the imagery and video evidence, and one-sided reports with unsubstantiated claims. When discovering deceptions and misinformation, it is thus critical to accurately characterize the sources, their posts, and associations between the imagery and textual knowledge in the posts.

In addition to analyzing the data fusion challenges in such an environment, we present the model for multi-source multi-modal data fusion, which can assist analysts in reconstructing the true state of the situation by aggregating the fragments of similar knowledge across text and imagery modalities and discarding deceptive information.

9474-31, Session 6

Weighted Kullback-Leibler average-based distributed filtering algorithm

Kelin Lu, Beihang Univ. (China); Kuochu C. Chang, George Mason Univ. (United States); Rui Zhou, Beihang Univ. (China)

In this paper, a novel data fusion solution to distributed filtering problem over multi-sensor network with unknown correlation between local estimations is proposed. The fusion rule is formulated by calculating the weighted Kullback-Leibler average of local estimates with consensus algorithms for distributed averaging, where the weighted Kullback-Leibler average is defined as an averaged probability density function that minimizes the sum of weighted Kullback-Leibler divergences from original probability density functions. In this sense, it is shown that the derived fusion rule actually coincides with the generalized covariance intersection algorithm, which is robust with respect to the unknown cross-covariance of local estimation errors. The main difference between the above two algorithms is that the former can be calculated in a distributed manner with consensus algorithms while the latter requires all local estimates to be available. Furthermore, in order to avoid obtaining a fused estimate that is too conservative, a novel consensus based distributed weighting coefficients selection scheme is developed to improve the fusion accuracy, where the weight associated with each sensor is adjusted based on the local estimation error covariance and the ones received from neighboring sensors so that larger weight values will be assigned to a sensor with higher belief. Finally, a Monte-Carlo simulation example for 2D tracking system validates the effectiveness of the proposed distributed filtering algorithm.

9474-32, Session 6

Categorification of the Dempster Shafer theory *(Invited Paper)*

Joseph J. Peri, Johns Hopkins Univ. Applied Physics Lab., LLC (United States)

This paper contains preliminary steps in demonstrating how the Dempster Shafer theory can be placed into the framework of category theory. In

the Dempster Shafer setting, the elements of the base set of a probability space are, typically, subsets of some set. Consequently, the elements of the corresponding sigma algebra are not subsets of a set, but rather, subsets of subsets of a set. A probability function, in this case, no longer has the classical meaning. This situation lends itself to the more general notions of inner and outer measures, which Shafer calls belief and plausibility, respectively. The categorical approach attempts to unify classical and non-classical concepts into a setting, so that, depending on the nature of the stochastic problem at hand, a general framework may be specialized appropriately to attack the problem.

9474-52, Session PSTue

Obstacle detection for unmanned ground vehicle in outdoor environment

Tok Son Choe, Jin-Bae Park, Yonsei Univ. (Korea, Republic of); Sang Hyun Joo, Yong Woon Park, Agency for Defense Development (Korea, Republic of)

An obstacle detection method for unmanned ground vehicle in outdoor environment is proposed. The proposed method uses range data acquired by laser range finders (LRFs) and FMCW radars. LRFs are used for distinguishing ground and obstacles on uneven terrain. The FMCW radars are used for detecting obstacles in dusty environment. The proposed obstacle detection algorithm is broadly composed by three steps: 1) 1D virtual range data generation which ground information is removed by range data of LRFs. The key ideas of step 1) is the use of two layers range data acquired by multiple or multi-layer LRFs to calculate the gradient of a target object. The target falls into ground or obstacles by the calculated gradient. The processed obstacle information is generated in the form of 1D range data. 2) 1D virtual range data generation acquired by fusion of multiple FMCW radars. In step 2), 1D range data which is virtually located on the same position of an LRF are generated. 3) 1D virtual range data generation which dust information is removed by range data fusion of step 1) and 2). In step 3), distance difference of range data acquired by LRFs and FMCW radars are compared with the reference value according to each horizontal angle. If distance difference is bigger than the reference value, it is determined that the environment is dusty. The range data generated by FMCW radars with respect to the corresponding angle is stored in the 1D virtual range data. The proposed method is verified by a real experiment.

9474-54, Session PSTue

Use of open space box: supporting tele-medicine in space through efficient data transmission

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

This paper presents a framework for a denormalized data ingestion and egress method which can be used among several types of in-space devices. Open Space Box is a novel model of communication that supports the data processing required to transform this data into products for utilization by the requesting stakeholders. One such set of data is the data that could be generated from a space-based 3D scanner. We provide an overview of 3D scanning technologies and discuss the storage/transmission needs and types of data generated by an optical 3D scanner developed and deployed at the University of North Dakota. Prospective usage patterns are discussed, as might be applicable to its use for regularly assessing astronauts' health and performing scientific experiments.

Communication of this sort of data may be critical to the health of astronauts and to scientific mission goals and ongoing operations. Some of this data may be processed even before it is transmitted to the attending healthcare provider or requesting scientist. Given that the data communications to and from a spacecraft or space station happens at a limited rate and the massive amounts of data that could be generated from 3D scanning, the receiver or egress application to prepare data needs to be designed to transmit and receive data via an application with a flexible protocol base. We consider the amount of data that could be generated by using the system for astronaut health monitoring, human experiments, non-human experiments and space station (or experiment, etc.) maintenance.

We discuss the efficacy of the Open Space Box approach for serving this need and discuss the particulars of the communications process. Serving these needs is enabled by the Open Space Box design. Under this, the request response happens in batch mode and the communication from 3D Scanner to the database, which is a NoSQL to store any type of data is done using YARN and MapReduce over a Hadoop cluster. The cost, reliability and efficacy of this approach are assessed and compared to conventional approaches.

9474-56, Session PSTue

On an efficiency and effective intelligent transportation system (ITS) safety and traffic efficiency applications with corresponding driver's behavior

Nnanna N. Ekedebe, Nicolas Dolphin, Towson Univ. (United States)

Many studies concur with the assertion that intelligent transportation systems (ITS)/vehicular ad hoc networks engender improvements respecting safety, and traffic efficiency applications. However, few have tried to evaluate these reported improvements in a heterogeneous driving environment with respect to human factor challenges.

Consequently, in this paper, we ascertain the effects of driver's behavior, concentration/distraction levels, age, etc. on reactions or responses to promptings/received messages displayed on a vehicles onboard unit (OBU) via the human machine interface (HMI) display. Our simulation input consists of six weeks realistic traffic data from the Maryland (MD)/Washington DC and Virginia (VA) areas from August 2012 to September 2012.

On very high level, our results show that the reported safety, and traffic efficiency improvements in ITS by several studies is mostly contingent on the alertness/concentration levels of the vehicle driver. Besides, our results can be used by transportation planning authorities and other concerned stakeholders in our reference study area to better comprehend the ramifications of full/partial ITS deployments in a realistic scenario.

9474-57, Session PSTue

Magnetic dipole parameter estimation and tracking using extended Kalman filter

Bhashyam Balaji, Bradley J. 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 Earth's ambient 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. 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, the measurement model was reviewed and it was shown in simulated data that the extended Kalman filter can be used to solve the problem for the scalar case (provided the initialization was appropriate). In

this paper, the algorithm is tested with real data collected with an airborne MAD sensor.

In order to work with real data, significant pre-processing is required. In particular, magnetic noise from platform motion must be modelled and removed, and a bandpass filter used to remove magnetic noise due to the underlying geology and temporal variations in the Earth's geomagnetic field in order to automate the detection processing. To apply the localization algorithm, however, one can either work with these bandpass filtered signals and band-pass filtered versions of the equations relating the measured MAD signature to the unknowns, or one can de-trend the unfiltered platform-noise reduced MAD signature and work with the unfiltered equations. In this work, the latter method has been used to provide the pre-processed signals for input to tracking filter. We investigate the performance of the interacting multiple model for a below-water dipole moving in a straight line at a constant speed whose signature is measured from a moving airborne platform equipped with a scalar magnetometer.

9474-58, Session PSTue

Bearing and frequency estimation using Cardiod sensors

Bhashyam Balaji, Rajiv Sithiravel, 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 manoeuvering 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.

9474-59, Session PSTue

The cubature smooth variable structure filter application into a quad-copter

Mohammad Al-Shabi, Philadelphia Univ. (Jordan); Stephen A. Gadsden, Univ. of Maryland, Baltimore (United States)

Nowadays, Unmanned Air Vehicles (UAVs) become increasingly popular in industrial, militarily and social applications. Many UAVs are available in stores with various kits including several frames, motors, sensors, controllers, and accessories. To have a UAV with good, stable, and robust performance, a higher price should be paid. To improve the response and accuracy of the UAV's performance while reducing the cost, an observer and/or a filter could be used. The observer/filter reduces the number of required sensors. Moreover, it improve the controller performance. As the system -under study- is highly nonlinear, deriving the filter becomes very challenging. In this paper, a new online state estimation algorithm that combines the Smooth Variable Structure Filter (SVSF) with the Cubature Kalman Filter (CKF) is proposed. The proposed method has robust, stable, and less sensitive to noise performance. A simulation study is used to estimate the states of a quad-copter demonstrating the results of the proposed method.

9474-33, Session 7

Learning representations for improved target identification, scene classification, and information fusion

Arjuna Flenner, Jennifer Flenner, Naval Air Warfare Ctr. Weapons Div. (United States); Michael Culp, Ryan McGee, Navy (United States); Cristina Garcia-Cardona, Los Alamos National Lab (United States)

The representation of an object is one of the crucial elements of Automated Target Recognition (ATR), and many approaches choose a basis, such as a wavelet or Fourier basis, to represent the target. Recent advancements in Image and Signal processing have shown that object recognition and denoising can be improved if a learned data representation is used rather than assuming a specific set of basis vectors. We discuss learning representations using Non-parametric Bayesian topic models, and demonstrate that the learned basis can improve ATR performance by 8% for vehicle identification. Non-parametric Bayesian analysis infers a data representation by assuming an infinite dimensional parameter space coupled with a clustering probability model that promotes a sparse set of learned basis vectors. Since the parameter space is infinite dimensional, the representation complexity can grow with new data, but the clustering probability model forces a reduced set of dictionary elements. In our particular object recognition problem, we use a bag of words model to represent images coupled with Poisson factor analysis. The bag of words model clusters image patches to generate image words in a vector quantization step and a histogram of image words is identified for each image, and the non-parametric Bayesian Chinese Restaurant process is used to identify the clusters. A non-parametric Bayesian approach to Poisson factor analysis is then used to learn a dictionary representation for these histograms. Poisson factor analysis exploits an additive property of the Poisson distribution to represent count data in the form of a basis vector and basis weights. Furthermore, we demonstrate how to generate models that integrate information from other sources without the need for registration. We apply the non-parametric technique to vehicle target identification and scene classification where we can improve identification by 4% if we integrate EO and IR information rather than using either modality separately. Furthermore, we demonstrate that we can integrate text and imagery to direct the representation for mission specific tasks and improve performance by 8%.

9474-34, Session 7

Effects of the experimental manipulation of Fourier components of naturalistic imagery on search performance and eye-tracking behavior

Alan R. Pinkus, Air Force Research Lab. (United States); James S. Garrett, Tiffany M Paul, Consortium Research Fellows Program (United States); Allan J. Pantle, Miami Univ. (United States)

Historically, visual search experiments used artificial stimuli (simple shapes) as targets and distractors arranged in an imaginary array of cells on a blank background. Little research on search behavior has been conducted with more naturalistic stimuli within a frequency-domain framework. With a common metric provided by Fourier analysis, it is possible to compare the effects of various frequency-domain components on search efficiencies with a variety of imagery, both artificial and naturalistic (Pinkus, Poteet,

and Pantle, 2013). In the current study, we experimentally manipulated the spectral content of target and distractor (background) cells filled with spatially filtered segments of real-life scenes. Our experimental design included two types of band-pass filters, orientation (some frequency overlap between target and distractors) and spatial frequency (no overlap), and two types of distractor compositions, uniform distractor (target and all distractors filtered similarly) and mixed distractor (only half of distractors filtered similar to the target) conditions. As predicted, subjects found the target more quickly and were more confident in their performance in the mixed condition. Subjects spent less time (fixation duration) and effort (fixation frequency) examining dissimilar distractors. Furthermore, subjects were faster, more accurate, and more confident in the spatial filter condition than in the orientation filter condition. The filter effect was magnified in the mixed distractor condition, likely due to the lack of frequency overlap in the spatial filter condition.

9474-36, Session 7

An infrared-visible image fusion scheme based on NSCT and compressed sensing

Qiong Zhang, Xavier Maldague, Univ. Laval (Canada)

Image fusion, as a research hot point nowadays in the field of infrared computer vision, has been developed utilizing different varieties of methods. Traditional image fusion algorithms are inclined to bring problems, such as data storage shortage and computational complexity increase, etc. Compressed sensing (CS) uses sparse sampling without knowing the priori knowledge and greatly reconstructs the image, which reduces the cost and complexity of image processing.

In this paper, an advanced compressed sensing image fusion algorithm based on non-subsampled contourlet transform (NSCT) is proposed. NSCT provides better sparsity than wavelet transform in image transformation. Throughout the NSCT decomposition, the low-frequency and high-frequency coefficients can be obtained respectively. For the fusion processing of low-frequency coefficients of infrared and visible images , the adaptive regional energy weighting rule is utilized. Thus only the high-frequency coefficients are specifically measured. Here uses sparse representation and random projection to obtain the required values of high-frequency coefficients, afterwards, the weights of each image block are calculated via adaptive standard deviation (ASD) method and are combined via weighted averaging. In the reconstruction, OMP (orthogonal matching pursuit) algorithm and TV (total variation) algorithm can be utilized to recover the high-frequency coefficients. Eventually, the fused image is recovered by inverse NSCT.

Both the visual effect and the numerical calculation after experiments indicate that the presented approach achieves high quality of image fusion, enhances targets and extracts more useful information.

9474-37, Session 7

Model-based detection, segmentation, and classification of compact objects

Mark J. Carlotto, General Dynamics Advanced Information Systems (United States)

A unified model-based approach to ATR that uses 3D models to control detection, segmentation, and classification is described. Objects are modeled by rectangular boxes whose dimensions are Gaussian random variables. A fast predictor estimates the size and shape of expected objects in the image, which controls detection and segmentation algorithms. Segmentation fits oriented rectangles (length x width @ pose) to object-like regions detected using a multi-level thresholding/region tracking approach. Detections are classified by comparing measured to predicted region length and width in the pose direction. The method is fast and requires only a coarse characterization of objects/object classes.

9474-38, Session 7

Change detection by extended image differencing applied to IR video

Günter Saur, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Change detection is one of the most important tasks when applying unmanned aerial vehicles (UAV) for video reconnaissance and surveillance. Here we address changes of short time scale, i. e. the observations are taken in time distances from several minutes up to few hours. Each observation is a short video sequence corresponding to the near-nadir overflight of the UAV over the interesting area and the relevant changes are e. g. recently parked or moved vehicles.

In this paper we apply our previous approach of extended image differencing for single video frames to video mosaics. A precise image-to-image registration combined with a robust matching approach is needed to stitch the video frames together to a mosaic. Additionally this matching algorithm is applied to mosaic pairs in order to align them to a common geometry. The resulting registered video mosaic pairs are the input of the change detection procedure based on extended image differencing. A change mask is generated by an adaptive threshold applied to a linear combination of difference images of intensity and gradient magnitude. The change detection algorithm has to distinguish between relevant and non-relevant changes. Examples for non-relevant changes are stereo disparity at 3D structures of the scene, changed length of shadows, and compression or transmission artifacts. The special effects of video mosaicking like geometric distortions and artifacts at moving objects, have to be considered too.

9474-39, Session 8

Search by photo methodology for signature properties assessment by human observers

Gorm K. Selj, Daniela H. Heinrich, Norwegian Defence Research Establishment (Norway)

Reliable, low-cost and simple methods for assessment of signature properties for military purposes are very important. In this paper we present such an approach that uses human observers in a search by photo assessment of signature properties of generic test targets. The method was carried out by logging a large number of detection times of targets recorded in relevant terrain backgrounds. The detection times were harvested by using human observers searching for targets in scene images shown by a high definition pc screen. All targets were identically located in each “search image”, allowing relative comparisons (and not just rank by order) of targets. To avoid biased detections, each observer only searched for one target per scene. Statistical analyses were carried out for the detection times data. Analysis of variance was chosen if detection times distribution associated with all targets satisfied normality, and non-parametric tests, such as Wilcoxon’s rank test, if otherwise. The new methodology allows assessment of signature properties in a reproducible, rapid and reliable setting. Such assessments are very complex as they must sort out what is of relevance in a signature test, but not loose information of value. We believe that choosing detection times as the primary variable for a comparison of signature properties, allows a careful and necessary inspection of observer data as the variable is continuous rather than discrete. Our method thus stands in opposition to approaches based on detections by subsequent, stepwise reductions in distance to target, or based on probability of detection.

9474-40, Session 8

Cross-modal face recognition using multi-matcher face scores

Yufeng Zheng, Alcorn State Univ. (United States); Erik Blasch, Air Force Research Lab. (United States)

The performance of face recognition can be improved using information fusion of multimodal images and multiple algorithms. When multimodal face images are available, cross-modal recognition is meaningful for security and surveillance applications. For example, a probe face is a thermal image (especially at nighttime), while only visible face images are available in the gallery database. Matching a thermal probe face onto the visible gallery faces requires cross-modal matching algorithms. A few such studies were implemented in facial feature space with medium recognition performance. In this paper, we propose a cross-modal recognition approach in face score space. In the proposed scenario, there are two face modalities (visible and thermal images) and three recognition algorithms (circular Gaussian filter, face pattern byte, linear discriminant analysis). A score vector is formed with three face scores from the aforementioned three algorithms. The cross-modal matching is implemented by a classifier (e.g., k-nearest neighbor [KNN], support vector machine, binomial logical regression) trained with the score vectors from thermal images while tested with the score vectors from visible images (or vice versa). The proposed approaches will be validated with a multispectral stereo face dataset from 105 subjects. Our preliminary experiments show very promising results: ACR (accuracy rate) = 97.72%, FAR (false accept rate) = 0.84% when cross-matching thermal face scores onto visible face scores using a KNN classifier. In the full paper, we will report the cross-matching performance after image fusion and feature fusion with the stereo images in our database.

9474-41, Session 8

Dimensionality analysis of facial signatures in visible and thermal spectra

Nathaniel Short, Booz Allen Hamilton Inc. (United States); Shuowen Hu, U.S. Army Research Lab. (United States); Prudhvi Gurram, MBO Partners (United States)

Face images are an important source of information for biometric recognition and intelligence gathering. While face recognition research has made significant progress over the past few decades, recognition of faces at extended ranges is still highly problematic. Recognition of a low-resolution probe face image in a gallery database, typically containing high resolution facial imagery, leads to low performance using traditional methods. Learning and super-resolution based approaches have been proposed to improve face recognition at extended ranges; however, the resolution threshold for face recognition has not been examined extensively. Establishing a threshold resolution corresponding to the theoretical and empirical limitations of low resolution face recognition will allow algorithm developers to avoid focusing on improving performance where no distinguishable information for identification exists in the acquired signal. This work examines the intrinsic dimensionality of facial signatures and seeks to estimate a lower bound for the size of a face image required for recognition. We estimate a lower bound for face signatures in the visible and thermal spectra by conducting eigenanalysis using principal component analysis (PCA) (i.e., eigenfaces approach). We estimate the intrinsic dimensionality/lower bound of facial signatures, in terms of reconstruction error, by maximizing the amount of variance retained in the reconstructed dataset while minimizing the number of reconstruction components. Extending on this approach, we also examine the identification error to estimate the intrinsic dimensionality with respect to low-resolution to high-resolution face recognition performance. Two multimodal face datasets are used for this study to evaluate the effects of dataset size and diversity on the underlying intrinsic dimensionality: 1) a 50-subject face dataset (containing visible, MWIR, LWIR face imagery) and 2) a 170-subject face dataset (containing visible and MWIR face imagery).

9474-43, Session 8

Muzzle flash localisation for the dismounted soldier

William J. Kennedy Scott, QinetiQ Ltd. (United Kingdom)

The ability to accurately and rapidly know the precise location of enemy fire would be a substantial capability enhancement to the dismounted soldier. Acoustic gun-shot detections systems can provide an approximate bearing but it is desired to precisely know the location (direction and range) of enemy fire; for example to know from 'which window' the fire is coming from. Funded by the UK MOD (via Chemring TS) QinetiQ is developing an imaging solution built around an InGaAs camera. However, providing such a capability to the dismounted soldier presents substantial challenges to develop a sensor that is sufficiently small, lightweight and low power but that has the required detection performance and all at an affordable cost. This paper presents work that QinetiQ has undertaken on the Muzzle Flash Locator system.

Key technical challenges that have been overcome are explained and discussed in this paper. They include; the design of the optical sensor and processing hardware to meet low size, weight and power requirements; the algorithm approach required to maintain sensitivity whilst rejecting false alarms from sources such as close passing insects and sun glint from scene objects; operation on the move; and constraining the algorithm design to exploit pipeline style processing. A real-time detection system which includes clutter rejection algorithms has been developed and has recently been demonstrated in a live fire trial. A summary of these results is presented and some interesting examples given. Next steps are discussed and include further algorithm development and integration with an acoustic gun-shot detection system.

9474-44, Session 8

The Locus analytical framework for indoor localization and tracking applications

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Obtaining location information can be of paramount importance in the context of pervasive and context-aware computing applications. Many systems have been proposed to date, e.g. GPS that has been proven to offer satisfying results in outdoor areas. The increased effect of large and small scale fading in indoor environments, however, makes localization a challenge. This is particularly reflected in the multitude of different systems that have been proposed in the context of indoor localization (e.g. RADAR, Cricket etc). The localization accuracy of such systems is often validated on vastly different test beds and conditions, making performance comparisons difficult and often irrelevant. The Locus analytical framework incorporates algorithms from multiple disciplines such as channel modeling, non-uniform random number generation, computational geometry, localization, tracking, probabilistic modeling, exploratory data analysis, graph theory etc. in order to provide: (a) fast and accurate signal propagation simulation in a clearly defined spatial scenario, (b) fast experimentation with localization and tracking algorithms and (c) an in-depth analysis methodology for estimating the performance limits of any Received Signal Strength (RSS) localization system. Simulation results for the well-known Fingerprinting and Trilateration algorithms are herein presented and validated with experimental data collected in real conditions using IEEE 802.15.4 ZigBee modules, operating in the 2.4 GHz ISM band. The analysis shows that the Locus framework accurately predicts the underlying distribution of the localization error and produces further estimates of the system's performance limitations in a best-case/worst-case scenario basis, focusing on various metrics of localization accuracy and precision. Thus, the proposed solution enables experimentation in both controlled simulated conditions and in near-real conditions, using external input of RSS measurements to properly model the propagation characteristics of the surrounding environment.

9474-47, Session 8

Range resolution improvement in passive bistatic radars using nested FM channels and least squares approach

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Passive Bistatic Radar (PBR) systems use illuminators of opportunity, such as FM, TV and DAB broadcasts. The most common illuminator of opportunity for the PBR systems is the FM radio stations. Single FM channel based PBR systems do not have high range resolution. In order to enhance the range resolution of the PBR systems algorithms using several FM channels at the same time are proposed [1, 2]. In standard methods, consecutive FM channels are translated to baseband as is and fed to the matched filter to compute the range-Doppler map. Multichannel FM based PBR systems have better range resolution than single channel systems. However superious side-lobe peaks occur as a side effect. Superious side-lobes are due to the cross-terms at the matched filter output. In this paper, we propose a new multichannel method based on both non-overlapping and overlapping baseband FM channels and deconvolution. We construct a new surveillance signal using both non-overlapped and overlapped baseband spectra of several FM channels using discrete-time processing. Following the rearrangement of FM channels in discrete domain, we construct the range-Doppler map using cross correlation based ambiguity function. In addition to this, we also construct another range-Doppler map using the autocorrelation of the constructed multi channel reference signal. Then using the range-Doppler map of crosscorrelation and autocorrelation, we estimate the positions of the targets by solving a deconvolution problem.

The proposed deconvolution algorithm is based on minimizing the distance between channel impulse response vector and the epigraph set of a convex cost function such as the l_1 norm [3]. Deconvolution with overlapping type multichannel FM signals is able to produce isolated peaks corresponding to the actual positions of the targets. However, deconvolution with non-overlapping type multichannel FM signals produces some superious peaks around the actual peak. In order to overcome the superious peaks, we relaxed the regularization term of the deconvolution algorithm. Both the overlapping ambiguity function approach and the modified least squares approach improve the range resolution and produce lower sidelobes than the ordinary multi-channel approach. Extensive simulation examples will be presented in the final form of the paper.

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9474-45, Session 9

Occlusion, optimization, emergency response and partial falls in a senior collapse detection system

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We discuss the further development of Senior Collapse Detection (SCD), a system that uses cyber-physical techniques to create a “smart home” system detect the falling of senior/geriatric participants in home environments. Specifically, we address the issues of Emergency Response to fall events, Optimization of Decision Factors, and also present techniques and testing to deal with occlusion. 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. To improve SCD’s robustness, we begin by introducing a new fall module that handles partial fall cases, a special-case not handled by our previous detectors. Next, we discuss the issue of how to find the optimal decision factors for determining falls, and present testing results of our optimized search algorithm. We then demonstrate the completed emergency response system for SCD which integrates speech recognition, text to speech, email, and SMS technologies. A problem with all vision systems is occlusion, and we discuss the problem as well as an initial attempt at efficiently handling one form of occlusion. Further results in a home environment will be given including test cases with supportive devices like “walkers” and canes are shown. 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 one solution to the ensuing problems of senior collapse.

9474-46, Session 9

Design for a source-agile automatic direction finder (ADF)

Harley R. Myler, Lamar Univ. (United States)

The design is intended for aircraft although any vehicle or even a man-mobile system could use the concept. An automatically reconfigurable antenna using MEMS RF switches is driven to seek signals consistent with the current location of the system. The antenna feeds a Software Defined Radio (SDR) that scans for signals and when a signal is found, it is identified and then the azimuth to the signal is used, along with a signal strength parameter, to confirm the location of the system. This is an extension of the now obsolete ADF aircraft navigation tool that used AM broadcast non-directional beacons (NDB), many of which are still in service. The current system can access any radio signal within the limits of the reconfigurable antenna and the SDR.

9474-48, Session 9

Engine classification using vibrations measured by laser Doppler vibrometer on different surfaces

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In our previous studies, vehicle surfaces’ vibrations caused by operating engines measured by Laser Doppler Vibrometer (LDV) have been effectively exploited in order to classify vehicles of different types, e.g., vans, 2-door sedans, 4-door sedans, pick-ups and buses, and different types of engines, such as Inline-four engines, V-6 engines, 1-axle diesel engines and 2-axle diesel engines. The results are achieved by employing methods based on a great array of machine learning classifiers such as AdaBoost, random forests, neural network and support vector machines. However, to achieve effective Intelligence, Surveillance and Reconnaissance (ISR) in utmost interest to military applications, signals directly picked up from vehicle surfaces are problematic: in a contested environment, enemies can intentionally change or conceal vehicle surfaces and thus compromising the vibration signals taken by the LDV thus counter-measuring the efficacy of the LDV’s remote sensing prowess. We hence need a more reliable approach to pick authentic vibrations of vehicle engines from a trustworthy surface, not the ones fully controlled by enemies.

Toward this end, we propose to pre-plant a number of retro-reflective and well-vibrating small objects such as flat metal sheets/bars along the road, so that when the vehicles move close to these objects their engines will cause the objects’ surface to vibrate, which in turn will be picked up by the LDV. Compared with vibrations directly taken from the uncooperative vehicle surfaces that are rigidly connected to the engines, these vibrations

are much weaker in magnitudes. However, the fact that they are difficult to be contaminated by enemies makes it an exceedingly appealing approach. In this work we conducted a systematic study on different types of objects that could be pre-planted in the environment. We tested different types of engines ranging from shavers, electric fans, and coffee machines over different surfaces such as white board, cement wall, and steel cases to investigate the characteristics of the LDV signals on these surfaces, in both the time and spectral domains. Preliminary results in engine classification using several machine learning algorithms point to the right direction on the choice of type of object surfaces to be planted for LDV measurements. This method has great potential to be exploited in contested, uncooperative environment for a more effective ISR.

9474-49, Session 9

Exploitation of vibrometry data

Karmon M. Vongsy, Air Force Research Lab. (United States); Ashley N. Smith, Wright State Univ. (United States)

Laser vibrometry provides a method to identify running vehicles' unique signatures using non-contact measurements. A vehicle's engine, size, materials, shape, and more vary its signature. To classify and identify these signatures, a robust aided target recognition (AiTR) end-to-end process is evaluated and expanded. Several challenges arise when classifying vehicles' vibration signatures. Operating conditions, parameters that vary such as weather, terrain, sensor location, sensor type, and engine speed, present the main challenge. Another challenge in vehicle classification is the determination of signal features that can overcome the differences created by these varying operating conditions. Eleven features taken from automatic speech recognition, seismology, and structural analysis were used in this end-to-end process. Features were selected by two feature selection methods to determine the best feature set for vehicle classification. Finally, four classifiers were used to identify vehicles' signatures. The classifiers' confusion matrices were used to make decisions on the end-to-end process. The entire process was tested on two small in-house data sets: a military vehicle collection using accelerometers and a civilian vehicle collection using a laser vibrometer and accelerometers.

9474-51, Session 9

Infrared small target detection algorithm based on multiscale codebook model

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With the continuous development of science and technology, infrared sensor technology has played an important role in national defense, medical, transportation and other areas. The tracking technology of small infrared target is an important branch of infrared imaging technology, which has not only very important scientific research value, but also has broad application prospect in the military and civil area.

Nowadays, different algorithms have been proposed for infrared target tracking. However, under complex backgrounds, such as clutter, varying illumination, and occlusion, the traditional tracking method often loses the real infrared small target.

To cope with these problems, in this paper we have present a novel infrared moving target detection algorithm based on multiscale codebook model according to the characteristics of small target in infrared images. The basic principles and the implementing procedure of these algorithms for target tracking are described. Firstly, the infrared video is stratified by Gauss Pyramid. Secondly, codebook model is built for each layer image and the moving target in infrared video is detected according to model. Finally, each layer results are combined and the final detection result is get. The experimental results show that, compared with traditional detection algorithms, the result of multiscale codebook model has better detection effects, richer target information and lower false detection rate. This algorithm can not only be used in the field of image fusion, in order to improve the fusion effect, but also be used in security surveillance, night vision surveillance and other civil and military fields.

9474-55, Session 9

The challenges of implementing and testing two signal processing algorithms for high rep-rate coherent Doppler lidar for wind sensing

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An eye-safe all-fiber 1.5 μm wavelength Coherent Doppler wind Lidar system has been developed and tested at the Optical Remote Sensing Laboratory of the City College of New York. The pulse energy is approximately 12μJ, the pulse repetition rate is 20 Khz and the data acquisition rate is 400 MHz so that sufficient signal integration is needed to make reliable velocity estimates with sub m/s resolution, assuming typical atmospheric backscatter conditions. Such constraints put demands on the digital signal processing (DSP) methods and techniques that are solved by implementing much of the DSP using a Field Programmable Gate Array (FPGA).

In this paper, we present two signal processing algorithms implemented using the FPGA. The first algorithm involves explicate time gating of received signals that correspond to a desired spatial resolution, performing a Fast Fourier Transform (FFT) calculation on each individual time gate, taking the square modulus of the FFT to form a power spectrum and then accumulating these power spectra over 10k return signals. The second algorithm involves calculating the autocorrelation of the backscattered signals and then accumulating the autocorrelation for 10k pulses. Efficient implementation of each of these two signal processing algorithms on an FPGA is challenging because it requires there to be tradeoffs between retaining the full data word width, managing the amount of on chip memory used and respecting the constraints imposed by the data width of the FPGA. A description of the approach used to manage these tradeoffs for each of the two signal processing algorithms are presented and explained in this article. Results of atmospheric measurements obtained through these two embedded programing techniques are also presented.

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9475-1, Session 1

SAR imaging using low-rank matrix recovery techniques

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In this paper we consider a synthetic aperture radar (SAR) transmitting. We present an image reconstruction method based on low-rank matrix recovery techniques. Numerical simulations show that low rank matrix recovery methods suppress the sidelobes of the point spread function better than conventional backprojection-based methods.

SAR scenes are often composed of a small number of strong scatterers or discontinuities, making SAR reflectivity function as sparse or low cardinality. These features make sparse signal recovery techniques suitable for SAR image reconstruction [5]. In this paper, we take an alternative approach and view SAR scenes as low-rank matrices and use matrix completion techniques to reconstruct SAR images. Matrix completion techniques were previously used in SAR imaging as a preprocessing step to synthesize measurements [1] and in array signal processing [3].

Imaging methods based on compressed sensing or low-rank matrix recovery techniques offer several advantages, they require far less measurements than conventional methods and produce better quality images.

We perform image formation using low-rank matrix recovery techniques. The methods rely on minimizing the rank instead of the cardinality of the image. We use the imaging operator presented in [2] to design the forward operator and a convex optimization program to minimize the nuclear norm, heuristic for the rank function.

In the final paper, we will present our problem formulation and image reconstruction in detail. We will present numerical simulations to demonstrate the performance of our imaging method.

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9475-2, Session 1

Analysis and sharpening of radar image reconstruction via debiasing the lasso

Il-Young Son, Birsen Yazici, Rensselaer Polytechnic Institute (United States); Edmund G. Zelnio, Uttam Majumder, Air Force Research Lab. (United States)

In radar imaging, the scatterers of interest are usually assumed to be spatially sparse. Thus, in a clutter-free environment, we can leverage this sparsity structure in the reconstruction of the reflectivity function to arrive at a sharper more focused image.

The theory of compressive sensing allows us to transform the usually intractable sparse recovery problem into a tractable one and gives the conditions under which one can achieve exact recovery [1], [2]. For noiseless case, one can solve an equivalent linear programming problem (i.e., convex relaxation of l0 to an l1 problem with linear constraints). For sparse reconstruction from noisy data, one can replace the linear constraints with constraints on the l2-norm of the residuals. The problem is then equivalent to the well-known Lasso regression problem [3] where an MMSE problem is regularized by a sparsity promoting l1-norm on the unknown vector. However, because the l1 regularization introduces bias, especially for high-dimensional problems, it is usually difficult to get an accurate handle on the distribution of the reconstructed image and hence difficult to analyze it statistically. Recent work by Javanmard et. al. [4] studied a new method for “debiasing” the Lasso solution that theoretically guarantees to give asymptotically unbiased results under sparsity assumption, provided certain conditions are met by the forward operator. Our goal in this study is to apply this technique for the radar imaging problem.

To this end, we explore the radar image reconstruction from limited data using sparse recovery techniques and leverage the recent theoretical results from Javanmard et. al. [4] to provide statistical analysis of the reconstruction in terms of confidence intervals. With the confidence intervals, we are able to assess the quality of the reconstruction without a priori knowing the true value of the reflectivity. Furthermore, by utilizing the p-value from the statistical analysis, we can perform spatially resolved detection on the reconstructed reflectivity function. We consider such debiased Lasso based reconstruction method for distributed sensors scenario, along with monostatic and bistatic SAR. We compare the results with conventional reconstruction methods and provide simulation results for comparison with the theoretical analysis. Namely we build confidence intervals for several realizations of the data with varying SNR and analyze the non-asymptotic bias term and compare with what is expected by the theory.

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9475-4, Session 1

Gradient projection for interrupted SAR using the polar format algorithm

Ross W. Deming, Solid State Scientific Corp. (United States); Chad Knight, Space Dynamics Lab. (United States) and Utah State Univ. (United States)

We present an efficient and computationally simple approach for synthetic aperture radar (SAR) imaging in cases where the radar data have gaps due to missing pulses and/or notches in the frequency band. Gaps in the data will typically produce bright streaks and other artifacts when using standard SAR algorithms. Mathematically, gaps in the data cause the imaging problem d = Ax to be underdetermined (fewer data samples d than image pixels x), so there are many image solutions x that will yield

the measured data d given the forward model A. A well-known strategy is to seek the solution x having minimum L1 norm, which increases image sparsity, and thus reduces bright streaks and other gap-related artifacts. The key is to choose a minimization scheme that converges quickly and avoids the storage and manipulation of large matrices. Various schemes include linear programming, Quasi-Newton methods, and gradient projection, among others. Our method is a computationally efficient version of gradient projection, in which the search path in each iteration is obtained by projecting the negative gradient of the L1 norm onto a hyperplane that defines solutions which are consistent with the data. The computations are not complicated since the L1 gradient is simply equal to the sign() of the pixels x in the image. Computational efficiency is obtained by incorporating the polar format algorithm, which projects intermediate images onto the solution hyperplane using a fast Fourier transform. Sample results are presented using the Air Force Research Laboratory's Gotcha airborne radar data set.

9475-5, Session 1

Back projection based Bistttic SAR DCPA for moving target imaging

Kaan Duman, Birsen Yazici, Rensselaer Polytechnic Institute (United States)

No Abstract Available

9475-6, Session 1

Knowledge-aided GMTI in a Bayesian framework

Michael Riedl, The Ohio State University (United States); Lee C. Potter, The Ohio State Univ. (United States)

Traditional ground moving target indicator (GMTI) processing attempts to separate moving objects in the scene from stationary clutter. Techniques such as space-time adaptive processing (STAP) require the use of an unknown covariance matrix of the interference (clutter, jamming, and thermal noise) that must be estimated from the remaining data not currently under test.

Many problems exist with estimating the interference covariance including: heterogeneous, contaminated, and/or limited training data. There are many existing techniques for obtaining an interference covariance matrix estimate, most of which incorporate some kind of prior knowledge to improve the estimate. We propose an approach that incorporates the knowledge of an approximate digital elevation map (DEM) and platform kinematics (platform velocity, crab angle, and antenna spacings) into a Bayesian framework that estimates both clutter and movers on a range by range basis without the explicit estimation of an interference covariance matrix. The signal model and required processing steps are detailed. We test our approach using the KASSPER I dataset and compare the results to other current approaches.

9475-7, Session 1

Clutter Suppression Interferometry System Design and Processing

Chad Knight, Space Dynamics Lab. (United States); Ross W. Deming, Solid State Scientific Corp. (United States); Jake Gunther, Utah State Universiy (United States)

Along track interferometry (ATI) processing has received extensive attention for its multi-modal capabilities. ATI has the ability to generate high-quality synthetic aperture radar (SAR) images and concurrently detect and estimate the positions of slow-moving targets with moderate processing. Previously demonstrated results have been impressive. However, radar systems used for ATI are often chosen by convenience and are not necessarily configured for optimal ATI/SAR performance. In this paper we focus on the ATI/SAR system configuration and the corresponding trade space where emphasis is given to the resource-constrained (e.g., UAV) environment. SDL has developed a simulation package and a flexible radar system called FlexSAR that allows for easy adjustment of the channels, channel baselines, waveforms, bandwidths, sampling, etc. This enables the simulation and collection of multi-static ground moving target indicator (GMTI) data. The multi-static configuration provides additional effective apertures and these collections therefore result in a larger effective baseline than standard (single transmitter) data collections using the same physical array. For example, a multi-static configuration with only two-physical antennas provides three effective apertures. This facilitates improved minimum detectable velocity (MDV) for both displaced phase center antenna (DPCA) and ATI processing, and also allows for clutter-suppression interferometry (CSI), which is critical for accurate cross-range estimation and improved results for endo-clutter geo-location. We discuss how these principles extend to higher dimensions, where N channels can provide (N/2)*(N+1) effective apertures, and consider the required system configuration. We initially examine several high fidelity time-domain SAR/ATI simulations to illustrate the trade space. We then examine actual multi-static GMTI results that were collected using the Space Dynamics Laboratory's (SDL's) FlexSAR system to illustrate the advantage of the proposed system configuration regarding target detectability and geo-location estimation.

9475-8, Session 1

Geolocation of moving targets in gotcha data using multimode processing

Unnikrishna Pillai, New York Univ. (United States); Ke Yong Li, C&P Technologies, Inc. (United States); Steven M. Scarborough, Air Force Research Lab. (United States)

No Abstract Available

9475-10, Session 2

SAR image statistics and adaptive signal processing for change detection

Viet T. Vu, Renato Machado, Mats I. Pettersson, Blekinge Institute of Technology (Sweden); Patrik Dammert, Hans Hellsten, Saab Electronic Defence Systems (Sweden)

The paper gives a research on SAR image statistics and adaptive signal processing for change detection.

Histograms are used to investigate SAR image statistics. A histogram provides us the information on the distribution of SAR image amplitudes or in other words the number of repetitions of SAR image amplitudes. The investigation shows that the distribution of SAR image amplitudes are quite close to the probability density function of the Rayleigh distribution. However, if two SAR images, which are subjects to detect changes, are combined with a simple linear subtraction, the distribution of this combination is approximately matched with the probability density function of the Gaussian or normal distribution.

This finding suggests that the Gaussian process dominates in the data obtained from the subtraction of two SAR images. The changes can be easier to be detected if the Gaussian process is removed from the data. The elimination can be simply based on any common adaptive noise cancellation mechanism. Adaptive line enhancer (ALE) is one example among adaptive noise cancellation mechanisms and does not require a separate reference signal.

In the experiment with the CARABAS data to illustrate the performance of ALE, a simple SAR scene with the known changes between two measurements is selected. Namely , 25 terrain vehicles concealed by foliage had been deployed in different parts of the SAR scene in the measurements.

The experimental results indicate that 19 among 25 terrain vehicles concealed by foliage can be securely detected using a simple adaptive signal processing mechanism like ALE. The performance of ALE for change detection depends strongly on how to select the parameters for ALE and the adaptive algorithm for ALE. There still exists the false alarms caused by, for example power lines, which need to be solved.

9475-11, Session 2

Signature predictions of surface targets undergoing turning maneuvers in spotlight synthetic aperture radar imagery

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This paper investigates methodologies for predicting the smear signatures in broadside spotlight synthetic aperture radar (SAR) imagery collections due to surface targets that are undergoing turning maneuvers. Analytic computation of a power series expansion of the subaperture phase function [Ref. 1] is used to compute a generic expression for the down-range and cross-range components of the predicted mover signature.

Studies of moving target signatures in SAR have revealed that the primary component of the smearing lies in the radar cross-range direction. However, there is also a slight component in the radar down-range direction, yielding moving target signatures that frequently have a curved or bowed shape. In fact, the details of the target motion and the radar collection contribute to the resulting location, extent, and shape of the resulting smear. One of the elements of the smear shape is whether the signature is curved upwards like a bowl towards near range or curved downwards like a hill towards far range.

The analytic expressions for the signature contours of turning targets are considered for typical SAR collections. The turning motion of a surface target introduces additional terms into the signature equations that can induce significant effects upon the resulting smear. In fact, these effects can reverse the concavity of a curved smear relative to a target that is moving with constant speed and heading. Numerous examples are presented to demonstrate that these signature prediction equations yield excellent agreement with simulated SAR smears. Therefore, these general signature prediction equations can provide an effective tool in predicting the shape, extent, and location of signature smears due to turning surface targets.

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9475-12, Session 2

Joint azimuth and elevation localization estimates in 3D synthetic aperture radar scenarios

Matthew P. Pepin, Sandia Staffing Alliance, LLC (United States)

The location of point scatterers in Synthetic Aperture Radar (SAR) data is exploited in several modern analyzes including persistent scatter tracking, terrain deformation, and object identification. The changes in scatterers over time (pulse to pulse including vibration and movement, or pass to pass including direct follow on, time of day, and season), can be used to draw more information about the data collection. Multiple pass and multiple antenna SAR scenarios have extended these analyzes to location in three dimensions. Either multiple passes at different elevation angles may be flown or an antenna array with an elevation baseline preforms a single pass. Parametric spectral estimation in each dimension allows sub-pixel localization of point scatterers in some cases additionally exploiting the multiple samples in each cross dimension. The accuracy of parametric estimation is increased when several azimuth passes or elevations (snapshots) are summed to mitigate measurement noise. Inherent range curvature across the aperture however limits the accuracy in the range dimension to that attained from a single pulse. Unlike the stationary case where radar returns may be averaged for better range estimates the movement necessary to create the synthetic aperture is only approximately (to pixel level accuracy) removed to form SAR images.

In parametric estimation increased accuracy is attained when two dimensions are used to jointly estimate locations. This paper involves jointly estimating azimuth and elevation to attain increased accuracy 3D location estimates. In this way the full 2D array of azimuth and elevation samples is used to obtain the maximum possible accuracy. In addition the independent dimension collection geometry requires choosing which dimension azimuth or elevation attains the highest accuracy while joint estimation increases accuracy in both dimensions.

Use of a 2D parametric estimation method attains the best accuracy possible in both dimensions. When in some scenarios, particularly the orbital case, where the azimuth dimension is only approximately linear the full accuracy increase of linear joint azimuth and elevation is not fully attained. Images and point cloud estimates are shown for several linear and orbital SAR scenarios. Images provide a visual representation of the data while the quantitative point cloud data is a direct input for the multiple analyzes listed earlier.

9475-13, Session 2

Impact of ground mover motion and windowing on stationary and moving shadows in synthetic aperture radar imagery

John Miller, Edward Bishop, General Atomics Aeronautical Systems, Inc. (United States); Armin W. Doerry, Ann M. Raynal, Sandia National Labs. (United States)

This paper describes the impact of ground mover motion and windowing on stationary and moving shadows in Synthetic Aperture Radar (SAR) and video SAR mode imagery. The technique provides a foundation for optimizing algorithms that detect ground movers in SAR imagery. The video SAR mode provides a persistent view of a scene centered at the Motion Compensation Point (MCP). The radar platform follows a circular flight path. Detecting a stationary shadow in a SAR image is important because the shadow indicates a detection of an object with a height component near the shadow. Similarly, the detection of a shadow that moves from frame to frame indicates the detection of a ground mover at the location of the moving shadow. An approach analyzes the impact of windowing in calculating the brightness of a pixel in a stationary, finite-sized shadow region. An extension of the approach describes the pixel brightness for a moving shadow as a function of its velocity. The pixel brightness provides an upper bound on the Probability of Detection (PD) and a lower bound on the Probability of False Alarm (PFA) for a finite-sized, stationary or moving shadow in the presence of homogeneous, ideal clutter. Synthetic data provides shadow characteristics for a radar scenario that lend themselves for detecting a ground mover. The paper presents 2011-2014 flight data collected by General Atomics Aeronautical Systems, Inc. (GA-ASI).

9475-14, Session 2

Asymptotic modeling of synthetic aperture ladar sensor phenomenology

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States); Edward A. Watson, Univ. of Dayton Research Institute (United States); Vincent J. Velten, Todd V. Rovito, Air Force Research Lab. (United States)

Interest in the use of active electro-optical sensors for non-cooperative target identification has steadily increased as the quality and availability of EO sources and detectors have improved. A unique and recent innovation has been the development of an airborne synthetic aperture imaging capability at optical wavelengths. To effectively exploit this new data source for target identification, one must develop an understanding of target-sensor phenomenology at those wavelengths. Current high-frequency, asymptotic EM predictors are computationally intractable for such conditions, as their ray density is inversely proportional to wavelength. As a more efficient alternative, we have developed a geometric optics based simulation for synthetic aperture ladar that seeks to model the second order statistics of the diffuse scattering commonly found at those wavelengths but with much lesser ray density. Code has been developed, ported to high-performance computing environments, and tested on a variety of target models.

9475-15, Session 2

Layover analysis in synthetic aperture radar images

Ling Wang, Nanjing Univ. of Aeronautics and Astronautics (China); Birsen Yazici, Rensselaer Polytechnic Institute (United States)

Layover is a phenomenon observed in range-based synthetic aperture radar (SAR) imaging due to unknown ground topography. For a fixed range, the scatterers at unknown elevation or height are “laid over” the scatterers that are at known heights in the image reconstruction process. Hence, the layover phenomenon prevents correct geocoding or positioning of scatterers at true two-dimensional map coordinates.

The analysis and impact of layover in SAR images have received significant attention [1-11]. However, the existing work in the literature is limited to certain imaging geometries and assumptions, such as straight linear antenna trajectories, relatively short synthetic apertures and far-field assumption. In this paper, we present a layover analysis applicable to arbitrary imaging geometries, monostatic and bistatic configurations, wide aperture imaging and curved wavefronts. Our work is based on microlocal analysis and provides explicit positioning errors in the reconstructed images due to unknown topography. While we consider backprojection (BP) type image formation [12-26], the analysis and results are also applicable to other SAR image formation methods. Under monostatic configuration, linear straight antenna and short aperture assumptions, our results reduce to the ones reported in [5, 6].

In the final paper, we will outline the theory in detail and present numerical simulations to demonstrate our analysis. While our analysis focuses on the layover phenomena observed in conventional SAR imaging, the analysis framework and methodology can be applied to understanding positioning errors due to unknown height error in other SAR modalities as well.

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9475-16, Session 2

Deep convolutional neural networks for ATR from SAR imagery

David A. E. Morgan, BAE Systems (United Kingdom)

Deep architectures for classification and representation learning have in recent years advanced the state-of-the-art across a diverse collection of problem sets including imagery, speech and text. In this study we benchmark the performance of a Deep Convolutional Neural Network (CNN) based approach to the classification of Synthetic Aperture Radar imagery. Furthermore, we explore how a machine learning approach to feature extraction could form the basis of a flexible Automatic Target Recognition (ATR) system that can be quickly adapted to incorporate previously unseen target types.

Training an ATR classification algorithm is typically a two stage process, the first being feature extraction and the second classification using the features. Whilst the use of either bespoke or generic features (e.g. wavelets) in classification can perform well, the former may not generalise well to new target types and the latter encodes no problem specific information and therefore performance depends entirely on the classifier. A Deep CNN approach blurs the distinction because relevant, discriminative features are elicited as part of the training process rather than being supplied as inputs to it.

We use recent concepts in Deep Learning, such as rectified linear units (ReLu), stochastic gradient descent training with momentum and dropout to train a CNN against the public release MSTAR data set. Results obtained for the 3-way and 10-way classification problems are competitive with existing, mature approaches in SAR literature. In addition, results obtained using a leave-one-out scheme show that a Deep CNN classifier trained against a 9-way classification problem can be quickly adapted to identify the previously unseen target.

9475-17, Session 2

Mixture of factor analyzers models of appearance manifolds for resolved SAR targets

Tarek Abdelrahman, Emre Ertin, The Ohio State Univ. (United States)

We study the problem of target identification from Synthetic Aperture Radar (SAR) imagery. SAR image classification is a challenging problem due to large variations of target signature as a function of aspect. Previous work on modeling wide angle SAR imagery have shown that point features derived from scattering center locations lie on a low dimensional manifold in high dimensional ambient space. We use rich probabilistic models of the target manifold for two key research tasks: first, for the analysis of target classification performance as a function of operating conditions and second, for the design of practical, scalable algorithms that can close the gap between existing algorithms and performance bounds. We employ Mixture of Factor Analyzers (MoFA) to provide probabilistic description of the manifold that can be used for both analysis and design. We optimize projection matrices to minimize probability of error in the projected space using high Signal-to-noise ratio (SNR) approximations and compare it to the empirical performance of Nearest Neighbor classification using data from Civilian Vehicle (CV) domes.

9475-18, Session 2

Sensitivity to number of quantization levels on quantization based ATR algorithm

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Previous SAR ATR efforts have yielded a class of algorithms that first quantize SAR images into N discrete bins. It is hypothesized that this process reduces the sensitivity of algorithm performance to nuisance parameters which are difficult to account for a priori. Additionally, these algorithms are simple in the sense that few tuning parameters are available, allowing for analytic analysis, and making these algorithms good candidates as 'baseline' algorithms to which more complex ATR solutions can be compared. Here we focus on two such algorithms: Multinomial Pattern Matching and Quantized Grayscale Matching.

These algorithms are known as model-based ATR algorithms, where each target/pose is class is assumed to be a generative statistical distribution and training the algorithm involves estimating the class-conditional parameter of each distribution using a set of truthed training images. MPM assumes that each image pixel is IDD according to a Dirichlet-Multinomial model and QGM assumes a simpler model where each pixel is an IID realization of only N IDD Multinomial random variables and hence the choice of N will affect each algorithm differently.

Here we investigate the issues arising for each algorithm based on the choice of N and attempt to derive an optimal choice based on maximizing the ATR performance as a function of the training datasets and subsequently the parameters for each in-class model.

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9476-1, Session 1

Target classification strategies

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Target classification algorithms have generally kept pace with developments in the academic and commercial sectors since the 1970s. However, most recently, investment into object classification by internet companies and various Human Brain Projects have far outpaced that of the defense sector. Implications are noteworthy.

There are some unique characteristics of the military classification problem. Target classification is not solely an algorithm design problem, but is part of a larger system design task. The design flows down from a concept of operations (ConOps) and key performance parameters (KPPs). Inputs are image and/or signal data and time-synchronized metadata. The operation is real-time. The implementation minimizes size, weight and power (SWaP). The output must be conveyed to a time-strapped operator who understands the rules of engagement. It is assumed that the adversary is actively trying to defeat recognition. The target list is often mission dependent, not necessarily a closed set, and may change on a daily basis. It is highly desirable to obtain sufficiently comprehensive training and testing data sets, but costs of doing so are very high and data on certain target types are scarce. The training data may not be representative of battlefield conditions suggesting the avoidance of highly tuned designs. A number of traditional and emerging feature extraction and target classification strategies are examined in the context of the military target classification problem.

9476-2, Session 1

Mutual information for enhanced feature selection in visual tracking

Victor Stamatescu, Anthony Milton, Univ. of South Australia (Australia); Sebastien Wong, Defence Science and Technology Organisation (Australia); Ivan Lee, David Kearney, Univ. of South Australia (Australia)

In this paper we investigate the problem of fusing a set of features for a discriminative visual tracking algorithm, where good features are those that best discriminate the object from the local background. This may be posed as a two-class object versus background classification problem. Discriminability may then be evaluated by using the Variance Ratio [1], which rewards features with small intra-class variances and large inter-class variance. Alternatively, discriminability may be evaluated using the Mutual Information between the class-conditioned feature responses and their corresponding classes [2]. However, an outstanding problem is that there may exist redundant information between any pair of feature responses within the selected subset of discriminative features. This effectively reduces the number of features within the subset, which in turn can reduce tracking robustness. Using a principled Mutual Information approach, we introduce a novel online feature selection algorithm that preserves discriminative features while reducing redundant information. Applying this algorithm to a discriminative visual tracking system, we experimentally demonstrate improved performance in tracking multiple objects using standard data sets.

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9476-3, Session 1

The effect of contrast in camouflage patterns on detectability by human observers and CAMAELEON

Daniela H. Heinrich, Gorm K. Selj, Norwegian Defence Research Establishment (Norway)

Evaluation of signature properties of military equipment is very important. It is crucial to apply the proper method out of many possible approaches, based on amongst others ranking by probability of detection, detection time, and distance to target, which have been carried out by various countries. In this paper we present results from camouflage pattern assessments utilizing two different approaches, based on i) human observers (detection time) and ii) simulations (CAMAELEON). CAMAELEON is a licensed tool that ranks camouflaged targets by their statistical overlap with the local background. The overlap is estimated through the parameters local contrast, orientation of structures in the pattern and spatial frequency, by mimicking the response/signal processing in the visual cortex of the human eye. In our camouflage tests, human observers were asked to search for targets (in natural settings) presented on a high resolution pc screen, and the corresponding detection times were recorded. In our study we find a good correspondence between the camouflage properties of the targets in most of our unique tests (scenes), but in some particular cases we found an interesting deviation. For two near-similar camouflage patterns (both were random samples of the local background) it seemed that the results depended on the way the pattern was assimilated to the test subject. More precisely, it may seem that high-contrast colored patches in the target outline were significantly different detected by humans compared to CAMAELEON. In this paper we discuss this deviation in the two signature evaluation methods and look at potential risks.

9476-4, Session 1

Evaluation methodology for query-based scene understanding systems

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In this paper, we are proposing a method for the principled evaluation of scene understanding systems in a query-based framework. We can think of a scene understanding system as a generalization of typical sensor exploitation systems where instead of performing a narrowly defined task (e.g., detect, track, classify, etc.), the system can perform general user-defined tasks specified in a query language. Examples of this type of system have been developed as part of DARPA's Mathematics of Sensing, Exploitation, and Execution (MSEE) program. There is a body of literature on the evaluation of typical sensor exploitation systems, but the open-ended nature of the query interface introduces new aspects to the evaluation problem that have not been widely considered before, including an unbounded query space from which we must draw our samples.

In this paper, we state the evaluation problem and propose an approach to efficiently learn about the quality of the system under test (SUT). We consider the objective of the evaluation to be to build a performance model of the SUT. We use Herbrand semantics to bound query space, and we rely on the principles of Bayesian experiment design to help construct and select optimal queries for learning about the parameters of the SUT performance model. Our methodology helps identify a) the atomic building blocks that

make up knowledge about the scene, b) new operating conditions that arise from the query-based paradigm, c) an outline of a proposed SUT performance model, d) query selection and update equations for the model, and e) a practical approach to generating and truthing queries.

9476-5, Session 2

Ambiguities of instantaneous frequency, and complex signal representations through pole-zero manipulations *(Invited Paper)*

Patrick J. Loughlin, Univ. of Pittsburgh (United States)

"Instantaneous frequency" is commonly defined as the derivative of the phase of a signal, which presupposes that we know the phase of the signal. But, there is an unlimited number of different amplitude-phase pairs that can generate the same real signal. Given the signal, which pair do we pick, and why? One procedure for obtaining a particular amplitude-phase pair of the real signal was given by Gabor, who associated a specific complex representation, called the analytic signal, to the real signal by suppressing the negative frequencies in the Fourier spectrum of the real signal. From the complex representation, the amplitude, phase and instantaneous frequency follow unambiguously. While the analytic signal is perhaps the most common method for obtaining "the" instantaneous frequency of a signal, many other methods, which yield different results, have been developed before and since. Of note is the approach of Poletti (IEEE TSP, 1997), who obtained complex representations not by direct manipulation of the spectrum of the real signal, but by manipulating the poles and zeros of the real signal in the complex time plane. Related work on instantaneous frequency and pole-zero manipulations in the complex time plane was done by Kumaresan and colleagues (JASA 1999, 2001). We discuss the basic issues and methods, and we extend the pole-zero approach to obtain complex signal representations by manipulating the poles and zeros not in the complex time plane, but in the complex frequency plane. We also discuss a common but fundamentally flawed way often used to compare and contrast various methods (namely by generating a signal via a particular a priori choice of amplitude-phase pair, and seeing how close the methods come to yielding that amplitude-phase pair); we suggest, instead, that the choice of a particular method must be driven by physical (or mathematical or physiological) properties. Some properties and their implications on the particular method used to obtain the instantaneous amplitude and frequency of a signal are discussed and illustrated.

9476-6, Session 2

A novel method for determining target detection thresholds

Stanley I. Grossman, National Geospatial-Intelligence Agency (United States)

Target detection is the act of isolating objects of interest from the surrounding clutter, generally using some form of test to include objects in the found class. However, the method of determining the threshold is overlooked relying on manual determination either through empirical observation or guesswork. The question remains: how does an analyst identify the detection threshold that will produce the optimum results? This work proposes the concept of a target detection sweet spot where the missed detection probability curve crosses the false detection curve; this represents the point at which missed detects are traded for false detects in order to effect positive or negative changes in the detection probability. Sensitivity curves are used to characterize detection probabilities and false alarm rates based on empirically derived data. It identifies the relationship between the empirically derived results and the first moment statistic of the histogram of the pixel target value data and then proposes a new method of applying the histogram results in an automated fashion to predict the target detection sweet spot at which to begin automated target detection.

9476-8, Session 2

Sparsity-driven anomaly detection for ship detection and tracking in maritime video

Scott Shafer, Joshua D. Harguess, Pedro Forero, Space and Naval Warfare Systems Ctr. Pacific (United States)

This work examines joint anomaly detection and dictionary learning approaches for identifying anomalies in persistent surveillance applications that require data compression. We have developed a sparsity-driven anomaly detector that can be efficiently used for learning dictionaries on-line to address these challenges. In our approach, each training datum is modeled as a sparse linear combination of dictionary atoms with noise. The noise term is modeled as additive Gaussian noise and a deterministic term models the anomalies. However, no model for the statistical distribution of the anomalies is made. We postulate an estimator for the dictionary that exploits the fact that since anomalies by definition are rare, when considering the entire dataset only a few anomalies will be present. From this vantage point, we endow the deterministic noise term (anomaly-related) with a group-sparsity property. A robust dictionary learning problem is postulated where a group-lasso penalty is used to encourage most anomaly-related noise components to be zero. The proposed estimator achieves robustness by both identifying the anomalies and removing their effect from the dictionary estimate. Our approach is applied to the problem of ship detection and tracking from full-motion video with promising results.

9476-9, Session 3

Vessel classification in overhead satellite imagery using weighted "bag of visual words"

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Vessel type classification in maritime imagery is a challenging problem and has applications to many military and surveillance applications. The ability to classify a vessel correctly varies significantly depending on its appearance which in turn is affected by external factors such as lighting or weather conditions, viewing geometry and sea state. The difficulty in classifying vessels also varies among different ship types as some types of vessels show more within-class variation than others. In our previous work, we showed that the "bag of visual words" was an effective feature representation for this classification task in the maritime domain. The bag of visual words (V-BoW) feature representation is analogous to the bag of words representation used in information retrieval (IR) application in text or natural language processing (NLP) domain. It has been shown in the textual IR applications that the performance of the bag of words (BoW) feature representation can be improved significantly by applying appropriate term-weighting and feature selection methods such as log term frequency, inverse document frequency etc. Given the close correspondence between textual BoW (T-BoW) and V-BoW feature representations, we propose to apply several well-known term weighting schemes from the text IR domain on V-BoW feature representation to increase its ability to discriminate between ship types. The impact of these feature weighting and selection methods on vessel type classification will be evaluated using different classification techniques.

9476-10, Session 3

Segmentation and tracking of electrokinetic particles in microscopic video

Qiang Le, Hampton Univ. (United States); Shizhi Qian, Old Dominion Univ. (United States)

Particle (both biological and synthetic) separation is a fundamental operation in many areas. Electrokinetics-based particle separation in microfluidic devices has been widely used for separating particles. To understand the electrokinetic particle motion in a microchannel, one could record the particle motion inside the microchannel as a video. The goal of the work is to segment the foreground particles and obtain their trajectories and velocities. Some of the challenges in our problem are the data association of particle targets due to the false alarms caused by the image segmentation, and the environmental noise.

In this work, we study two microscopic videos. Video 1 is 11 seconds with 290 frames where a typical frame consists of twelve particles moving inside a single microchannel and the motion of a particle lasts about 60 frames. Video 2 is 40 seconds where a frame consists of up to twenty particles moving in two separated microchannels. We aim to obtain the trajectory and velocity of our interested particles from the movies.

The framework we propose to track the particles consists of the target segmentation and the multiple- target tracking filter. In the segmentation, we use the morphological operations (a bundle of dilation, erosion and connected component based region analysis) to segment the foreground particles. As a result, a binary image of highlighted particles is generated. Then the centroids of particles are used as the measurements per frame in the multiple-target tracking filter. Finally, the multiple hypothesis tracking (MHT) coupled with the kalman filter (KF) is used to tackle the data association and obtain the particle trajectories. The global hypothesis is defined as a set of disjointed particle tracks that do not share the same measurements. We use the integer linear programming technique to obtain the best hypothesis that minimizes the accumulated distance cost in a time window. In addition, new target appearance and target termination management will be considered in the paper.

9476-11, Session 3

Shape distance transform for morphological filtering and landing site selection

Bing C Li, Lockheed Martin Systems Integration-Owego (United States)

Morphological filtering, erosion and dilation on images, has been successfully applied to many image processing and pattern recognition applications. Landing site selection, finding the best (safest) point to land with given obstacle distributions and aircraft shapes, has significant value for landing aircraft in tight environments. In this paper, we derive the shape transform theory, and use this theory to build a connection between morphological filtering and landing site selection which seem to be different problems. By developing a fast implementation of the shape distance transform, we propose new techniques for both fast morphological filtering and fast computation of landing site selection.

First, we derive the shape distance transform theory, and show that the distance between two points is determined by a predefined shape and its scale factor (zoom in and zoom out). We then demonstrate the relationship of the shape distance transform theory to some popular distance transforms, and show that those popular distance transforms are the shape transform with specific shapes. For example, when circles are chosen as the predefined shape, the shape distance transform is equivalent to the Euclidean distance transform, while when choosing square shapes, we can use the chessboard distance transform. When we choose other shapes, we will obtain other different distance transforms.

Next, we show that morphological filtering and best landing site selection can be converted into the shape distance transform. Morphological filtering of a binary image can be generated by thresholding its shape distance transform image while the optimal landing site is at the maximum distance point. Then we discuss a special type of shape distance transform, convex polygon shape distance transform. In this transform, convex polygons are chosen as the base shapes. Since any convex shape can be approximated by convex polygons, the convex polygon shape distance can be used to approximately implement morphological filtering or optimal landing site selection with any convex shapes including convex polygons.

In order to improve the computational efficiency, we propose a line distance propagation approach to compute the convex polygon shape distance transform. With this new implementation, we develop a mask size independent implementation of morphological filtering that reduces the computational complexity for calculating each pixel value from O(N) to O(1) where N is the number of pixels for a filtering mask. Finally, we apply the shape distance transform to morphological filtering and landing site selection, and show that the new implementation significantly reduces their computational cost.

9476-12, Session 3

An approach to automatic detection of suspicious individuals in a crowd

Stephen Lucci, Satabdi Mukherjee, Izidor Gertner, The City College of New York (United States)

This paper describes an approach to detect individuals with suspicious objects in a crowd. It is based on a well-known image retrieval problem as applied to mobile visual search. In many cases, the process of building a hierarchy tree uses k-means clustering followed by a geometric verification. However, the number of clusters is not known in advance, and sometimes it is randomly generated. This may lead to a congested clustering which can cause problems in grouping large real-time data. To overcome this problem we have applied the Indian Buffet stochastic process approach in this paper to the clustering problem. We present examples illustrating our method.

9476-13, Session 4

Empirical evaluation of standard tracking process models and proposed enhancements

Bhargav R. Avasarala, Northrop Grumman Corp. (United States); Ryan Turner, Steven Bottone, Northrop Grumman Corp. (United States); Clay J. Stanek, Northrop Grumman Corp. (United States)

Kalman filters and their nonlinear extensions (extended Kalman filter and unscented Kalman filter) have been successfully utilized in many practical applications for performing efficient state estimation. However, most implementations make use of ad-hoc or apriori knowledge to set the necessary tuning parameters, such as those describing the process noise, which may not generalize to other applications. We employ modern statistical machine learning techniques to intelligently select these parameters using all available data. We also explore whether the standard Kalman filter approach is the most empirically appropriate model by considering other time series models, such as Gaussian processes, and benchmark their performance. We evaluate our techniques using a large volume of commercially available, high-resolution automatic dependent surveillance-broadcast (ADS-B) and aircraft situation display to industry (ASDI) data, consisting of thousands of flight trajectories.

9476-14, Session 4

Aided target recognition using hyperdimensional manifolds

Shih-Chi K. Chen, Robert Stanfill, Abhijit Mahalanobis, Lockheed Martin Missiles and Fire Control (United States)

We explore the use of hyperdimensional manifolds on Aided Target Recognition (AiTR) using Synthetic Aperture Radar (SAR) imagery. Data that occupies within a hyperdimensional space can be exploited using measures constrained along the inherent structure (manifold). When compared to multiple manifolds representing different classes, associations can be made by utilizing these constrained measures and data clusters to assign to the closest class. We also explore the use of sparsely estimated manifolds (limited training data) and its impact on AiTR results on SAR imagery.

9476-44, Session 4

Recognizable 3D scene reconstruction from 2D imagery with deep learning

Timothy S. Khuon, Michael J. Laielli, Robert S. Rand, National Geospatial-Intelligence Agency (United States)

Light that enters the human eye is refracted as it passes through the cornea and then passes through the pupil. The cornea and lens act together as a compound lens to project an up-side-down image onto the retina. The scene obtained on the retina is 2D imagery. However, the visual system, being a part of the central nervous system, gives organisms the ability to process visual detail. It detects and interprets information from light spectrum to build a representation of the surrounding environment in 3D imagery.

In the current study, we attempt to simulate the mechanism as described above. With a given photograph in 2D imagery, we utilize the Deep Learning as the visual system to transform it into a 3D imagery. Furthermore, all objects in the imagery are extracted, analyzed and recognized for a comprehensive scene reconstruction. For a man-made object in the scene such as building or sport complex, it can be extracted for 3D modeling. For single-modal data, target recognition and classification in an imagery 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. Therefore, an adaptive system with a specific desired tolerance is required to perform classification and recognition optimally. A Deep Learning-based feature-based pattern recognition algorithm is generalized for solving a particular global problem without loss of generality.

This study combines the adaptive deep learning and automatic target recognition. The Boltzmann Machine class is used for the non-linear and adaptive learning machine; particularly, the restricted Boltzmann machine (RBM), which is a generative stochastic artificial neural network that can learn a probability distribution over a set of inputs. The RBM applications includes dimensionality reduction, classification, and feature learning. They can be trained in either supervised or unsupervised ways, depending on the task.

9476-16, Session 5

Enhanced target versus clutter discrimination using time-frequency (LTV) filters *(Invited Paper)*

Vikram T. Gomatam, Patrick J. Loughlin, Univ. of Pittsburgh (United States)

In active sensing such as in sonar and radar, target recognition is adversely impacted by target-like returns from non-target objects (i.e. clutter). While optimal classifiers can be designed to differentiate targets from clutter, the statistics of the return echoes may not always adhere to the assumptions underlying optimality (e.g., Gaussian PDFs). We implemented a minimum probability of error (MPE) classifier with linear time-varying (LTV) pre-filters to distinguish targets from clutter in active sonar data. Classification performance was substantially improved compared to applying the MPE classifier to the non-LTV filtered data.

9476-17, Session 5

Stereo image segmentation with application in underwater fish detection and tracking

Dimitrios Charalampidis, Madhuri Gundam, George E. Ioup, Juliette W. Ioup, Univ. of New Orleans (United States); Charles H. Thompson, National Marine Fisheries Service (United States)

Most often, background subtraction and image segmentation methods use images or video captured using a single camera. However, segmentation can be improved using stereo images by reducing errors caused due to illumination fluctuations and object occlusion. This work proposes a background subtraction and image segmentation method for images obtained using a two camera stereo system. Stereo imaging is often employed in order to obtain depth information. On the other hand, the objective of this work is mainly to extract accurate boundaries of objects from stereo images, which are otherwise difficult to obtain. Improving the outline detection accuracy is vital for object recognition applications. An application of the proposed technique is presented for the detection and tracking of fish in underwater image sequences. Outline fish detection is a challenging task since fish are not rigid objects. Moreover, color is not necessarily a reliable means to segment underwater images, therefore, gray scale images are used. Due to these two reasons, and due to the fact that underwater images captured in non-controlled environments are often blurry and poorly illuminated, commonly used local correlation methods are not sufficient for stereo image matching. The proposed algorithm improves segmentation in several scenarios including cases where fish are occluded by other regions, when fish have gray scale intensities similar to the background, and for cases of non-stationary background such the moving sea-weed. Although the work concentrates on fish detection and tracking, it can be employed for other underwater image segmentation applications where visible-light cameras are used.

9476-18, Session 5

Types and classification of noises *(Invited Paper)*

Leon Cohen, Hunter College (United States)

There are many types of noises that have been studied, the most famous being white Gaussian noise. Knowing the statistics of a noise is crucial for the detection problem. We develop a method to generate and classify noises in a systematic way and in particular we study noises that change in both space and time (reverberation noise for example). Of particular importance is noise in a waveguide with dispersion. We discuss the mathematical characterization of non-Gaussian noises and under what circumstances they are generated.

9476-19, Session 5

Why the inverse scattering by topological sensitivity may work

Bojan Guzina, Fatemeh Pourahmadian, Univ. of Minnesota, Twin Cities (United States)

This study deciphers the topological sensitivity as a tool for imaging anomalies in the high-frequency regime, where the germane wavelength is surpassed by the remaining length scales in the problem. It is assumed that the anomaly i.e. obstacle is convex and impenetrable, and that the measurements of the scattered field are taken over a sphere whose radius is large relative to the size of the interrogated region. In this setting, the formula for topological sensitivity – which quantifies the perturbation of a cost functional due to introduction of a point- like scatterer – is expressed as a pair of nested surface integrals: one taken over the boundary of a hidden obstacle, and the other over the measurement surface. Using multipole expansion, the latter integral is reduced to a set of antilinear forms featuring the Green's function and its gradient. The remaining expression is distilled by evaluating the scattered field on the surface of an obstacle via Kirchhoff approximation, and pursuing the asymptotic expansion of the remaining Fourier integral. In this way the topological sensitivity is found to survive upon three asymptotic lynchpins, namely i) the near-boundary approximation for sampling points close to the "exposed" surface of an obstacle; ii) uniform expansions synthesizing the diffraction catastrophes for sampling points near caustic surfaces, lines, and points; and iii) non-uniform (stationary phase) approximation. Within the framework of the catastrophe theory it is shown that, in the case of the full source aperture, the topological sensitivity is asymptotically dominated by the (explicit) near-boundary term – which explains the previously reported reconstruction capabilities of this class of indicator functionals. The analysis is illustrated by numerical results and an application to a recent set of experimental data.

9476-20, Session 5

Knowledge-directed adaptive automated underwater sonar mine detection and classification

Firooz A. Sadjadi, Lockheed Martin Corp. (United States)

This paper addresses the issue of underwater automatic object detection and classification of mine-like objects by means of a sonar sensor. The proposed method adaptively selects the optimum algorithms and their parameters as sensor parameters and environmental conditions change. For adaptation, the method exploits predictive performance models of target detection and classification in terms of sea state, sensor and environmental parameters, target detection and classification algorithms and their internal parameters. The results of the application of the method on real and physics-based simulated data will be presented.

9476-21, Session 6

Performance of Peaky Template Matching Under Additive

White Gaussian Noise and Uniform Quantization

Matt S. Horvath, Brian D. Rigling, Wright State Univ. (United States)

Typical ATR performance evaluation methodologies usually require empirically evaluating algorithm performance using a baseline truthed dataset. Accounting for the wide variety of operating conditions the algorithm may encounter in an operational capacity in this dataset is intractable, leaving the potential for unknown performance. Additionally, this type of performance analysis does not yield insight into why the algorithm performed either poorly or acceptably.

In order to overcome these shortcomings, we focus on deriving analytic approximations to the performance of two quantization based ATR algorithms, Multinomial Pattern Matching (MPM) and Quantized Grayscale Matching (QGM), under the AWGN OC. These algorithms have demonstrated utility in SAR ATR due to hypothetically reducing the performance sensitivity to nuisance parameters that are difficult to account for. Here we focus specifically on the AWGN operating condition, which is not a major issue in SAR ATR performance, however is a consideration for other sensor modalities such as FLIR and LADAR.

To these ends, we develop analytic performance approximations to the MPM and QGM image-to-template and template-to-template match scores for both the the binary classification problem as well as the detection problem. These algorithms are known as model-based ATR algorithms, where each target/pose is class is assumed to be a generative statistical distribution and training the algorithm involves estimating the class-conditional parameter of each distribution using a set of truthed training images. MPM assumes that each image pixel is IDD according to a Dirichlet-Multinomial model and QGM assumes a simpler model where each pixel is an IID realization of only two IDD Multinomial random variables.

We verify the results of our analysis using Monte Carlo simulations with the ARL Comanche dataset.

9476-22, Session 6

Performance and time requirement analysis of top-hat transform based small target detection

Ozan Yardımcı, Seyit Tunc, Roketsan Roket Sanayii ve Ticaret A.S. (Turkey); Ilkay Ulusoy Parnas, Middle East Technical Univ. (Turkey)

With the rapid development of digital image acquisition and processing technology, automatic target detection has become applicable in civilian and military fields such as guidance and automatic control. Automatic target detection can be done by processing a single frame or by processing successive frames in a moving camera system. These two approaches have some advantages and disadvantages when compared to each other. Algorithms related to single frame target detection from cluttered background usually starts with image enhancement. Max-mean filter, max-median filter, frequency filter, wavelet filter and mathematical morphology have been used for target enhancement. In this paper, we focused on mathematical morphology and especially the Top-Hat transform, which has been proved to be very useful for small target detection. There are some challenging problems that need to be solved in the Top-Hat transform based methods. For example, it is difficult to find a correct structure element size and shape, without knowing the possible target size and shape. Also, false alarm rate can be very high and various pre-processing or post-processing should be applied to prevent this.

In this paper, we investigate various different Top-Hat transformation based small target detection approaches which are compared using the same test images. The comparison among them is done in terms of three issues: 1. the detection performance (precision and false alarm rate), 2. the time requirement of the method and its usability for real time applications, 3. the number of parameters, which need to be tuned manually. Results show that knowing the possible target size a priori is very important for a high performance. This information may be used either as the structuring element size or as the threshold for post processing. Automatic approaches to estimate the parameters may not be generic enough to be applied to various images. But adaptive approaches for estimating the image specific threshold value, perform better than the others.

9476-23, Session 6

An evaluation of open set recognition for FLIR images

Matthew Scherreik, Brian D. Rigling, Wright State Univ. (United States)

Typical supervised classification algorithms label inputs according to what was learned in a training phase. Thus, test inputs that were not seen in training are always given incorrect labels. Open set recognition algorithms address this issue by accounting for inputs that are not present in training and providing the classifier with an option to "reject" unknown samples. A number of such techniques have been developed in the literature, many of which are based on support vector machines (SVMs). One approach, the 1-vs-set machine, constructs a "slab" in feature space using the SVM hyperplane. Inputs falling on one side of the slab or within the slab belong to a training class, while inputs falling on the far side of the slab are rejected. We note that rejection of unknown inputs can be achieved by thresholding class posterior probabilities. Another recently developed approach, the

Probabilistic Open Set SVM (POS-SVM), empirically determines good probability thresholds. We apply the 1-vs-set machine, POS-SVM, and closed set SVMs to FLIR images taken from the Comanche SIG dataset. Vehicles in the dataset are divided into three general classes: wheeled, armored personnel carrier (APC), and tank. For each class, a coarse pose estimate (front, rear, left, right) is taken. In a closed set sense, we analyze these algorithms for prediction of vehicle class and pose. To test open set performance, one or more vehicle classes are held out from training. By considering closed and open set performance separately, we may closely analyze both inter-class discrimination and threshold effectiveness.

9476-24, Session 6

Automatic solar panel recognition and defect detection using infrared imaging

Xiang Gao, Eric Munson, Arizona State Univ. (United States); Glen Abousleman, General Dynamics C4 Systems (United States); Jennie Si, Arizona State Univ. (United States)

Failure-free operation of solar panels is of fundamental importance for a modern commercial solar power plant. To achieve higher efficiency in power generation and longer life of the panels a simple and reliable evaluation method is required. By using thermal infrared imaging, anomalies can be detected when the panels are under normal operation. In this paper we propose a solar panel defect detection system which greatly automates the inspection process. Infrared video sequences are first collected from an infrared camera mounting on a moving cart which is driving from row to row in a solar farm. Then the image processing algorithm running on a laptop computer segments the solar modules from the background in real-time. Prior information of a solar array, like how many rows in that array, need to be specified before segmentation because position of missing rows need to be estimated if the feature detection fails due to low image quality. In order to continually number the modules, frame-to frame module association is established by optical flow. Local anomalies in a single module like hotspots and cracks will be immediately detected and labelled as soon as the module is recognized in the field of view. After the data of the whole array is collected, hot modules are detected using DBSCAN clustering. Solutions to several challenging scenarios like occlusions, motion blur, shadows and sun reflection on the panels are also discussed and proposed. This system has been tested on a real dataset which contains over 12,000 solar modules and demonstrates desired ability to detect the anomalies. Over 98% of all modules are recognized and correctly numbered, and 92% of all types of defects are identified by the system. We find that it can greatly mitigate the tedious routine of panel inspection in a large solar farm.

9476-25, Session 7

Estimation, tracking and geolocation of maritime burst signals from a single receiver *(Invited Paper)*

Douglas J. Nelson, National Security Agency (United States); Jeffrey N. Townsend, U.S. Dept. of Defense (United States)

We present methods for estimating the source locations of a narrowband signals in a multi-signal environment. These methods require only a single receiver and are based only on the estimated frequencies of the received signals. These methods may be used to estimate the emitter location in three dimensions, making it possible to locate the target without DTED elevation data. Frequency estimation and tracking is accomplished using cross-spectral frequency estimation and polynomial tracking methods previously presented. We further demonstrate that multiple received signals may be deinterleaved and tracked by statistical methods based on received frequency and rate of change of frequency.

The methods presented are based on a model of ship-borne transmitters, such as radar signals and the maritime AIS signal. We have previously reported methods for geolocating communication signals, such as analog FM speech and binary phase shift keyed (BPSK). Unlike our previously reported methods, the signals considered for this effort are transmitted in short bursts that may be sparsely transmitted. These signals may have significant co-channel interference and are difficult to accurately frequency track due to the short pulse (burst) duration. The methods presented are based on the previously demonstrated ability to estimate and track the carrier, even in co-channel interference.

Geolocation methods have been tested and evaluated on data collected from cooperative tests and on high quality simulations that model test conditions involving multiple transmitters and receivers in arbitrary configurations.

9476-26, Session 7

Multisensor fusion with the ramification algorithm *(Invited Paper)*

Andre U. Sokolnikov, Visual Solutions and Applications (United States)

The present approach combines data fusion from several sensor types to enhance the overall detection and classification performance. The fusion of different sensors is implemented at data and feature levels that results in enhanced target identification by the means of spatial-spectral analysis.

9476-27, Session 7

Distributed estimation of a parametric field with random sensor placements *(Invited Paper)*

Marwan Alkhweldi, Zhicheng Cao, Natalia A. Schmid, West Virginia Univ. (United States)

This paper considers a problem of distributed function estimation in the case when sensor locations are modeled as Gaussian distributed random variables. We consider a scenario where sensors are distributed in clusters with cluster centers known a priori (or estimated by a high performance GPS) and the average quadratic spread of sensors around the cluster center also known. Distributed sensors make noisy observations about an unknown parametric filed generated by a physical object (for example, magnetic field generated by a ferrous object and sensed by a network of magnetometers). Each sensor will then perform local signal processing of its noisy observation and sends it to a central processor (often called fusion center) in the wireless sensor network over parallel channels corrupted by fading and additive noise. The central processor combines the set of received signals to form an estimate of the unknown parametric field. In our numerical analysis, we involve a filed shaped as a Gaussian bell. We experiment with the size of sensor clusters and with their number. It can be shown that a relatively good estimate of the field can be obtained with a single cluster. As the number of clusters increases, the estimation performance steadily improves. The results also indicate that, in the average, the number of clusters has more impact on the performance than the number of sensors per cluster, given the same size of the total network. Numerically evaluated mean square error between the estimated parameters of the field and the true parameters used in simulations are compared to values of Cramer Rao Lower Bound.

9476-28, Session 7

Inferential statistics for transient signal detection in radio astronomy phased arrays *(Invited Paper)*

Natalia A. Schmid, West Virginia Univ. (United States); Richard M. Prestage, National Radio Astronomy Observatory (United States); Marwan Alkhweldi, West Virginia Univ. (United States)

In this paper we develop two statistical rules for the purpose of detecting pulsars and transients using signals from phase array feeds installed on a radio telescope in place of a traditional horn receiver. We assume a known response of the antenna arrays and known coupling among array elements. We briefly summarize a set of pre-processing steps applied to raw array data prior to signal detection and then derive two detection statistics assuming two models for the unknown radio source astronomical signal: (1) signal is deterministic and (2) signal is a random process. The performance of both detectors is analyzed using simulated data.

9476-29, Session 7

Composite multi-lobe descriptor for cross spectral face recognition: matching active IR to visible light images *(Invited Paper)*

Zhicheng Cao, Natalia A. Schmid, West Virginia Univ. (United States)

Matching facial images across electromagnetic spectrum presents a challenging problem in the field of biometrics and identity management. An example of this problem includes cross spectral matching of active infrared (IR) face images or thermal IR face images against a dataset of visible light images. This paper describes a new operator named Composite Multi-Lobe Descriptor (CMLD) for facial feature extraction in cross spectral matching of near infrared (NIR) or short wave infrared (SWIR) against visible light images. The new operator is inspired by the design of ordinal measures. The operator combines Gabor filter, Local Binary Pattern (LBP) and generalized LBP (GLBP), Weber Local Descriptor (WLD) and modifies them into multi-lobe functions with smoothed neighborhoods. The new operator encodes both magnitude and phase responses of the Gabor filter. The combining of LBP and WLD utilizes both the orientation and intensity information of edges. Introduction of multi-lobe functions with smoothed neighborhoods further makes the proposed operator robust against noise and poor image quality. Output templates are transformed into histograms and then compared by means of a symmetric Kullbuck-Leibler metric resulting in a matching score. The performance of the multi-lobe operator is compared with that of other operators such as LBP, WLD, HOG, ordinal measures, and their combinations. The experimental results show that in many cases the proposed method, CMLD, outperforms the other operators and their combinations. In addition to different infrared spectrum, various standoff distances from close-up (1.5 m) to intermediate (50 m) and long (106 m) are also investigated in this paper. Performance of CMLD is evaluated for of each of the three cases of distances.

9476-30, Session 7

Identification of partially occluded firearms through partonomy *(Invited Paper)*

Abdullah N. Arslan, Christian F. Hempelmann, Salvatore Attardo, Grady P. Blount, Texas A&M Univ.-Commerce (United States); Nona N Sirakova, Redmond (United States); Nikolay M Sirakov, Texas A&M Univ.-Commerce (United States)

In the present paper we study the problem of weapon identification and threat assessment from a single image with partially occluded weapon. This problem poses very severe restrictions and requires sophisticated methods to reach a solution. To successfully identify a weapon from its parts we extend the first firearm ontology with the meronymic (partonomic) principles which will let us distinguish functionally defined parts as well as parts that are essential to a gun (lock, barrel) from parts that are not essential (stock, scope). These distinctions are relevant for assessing the threat that a disassembled or assembled gun may pose, as well as for identifying a gun that is partially occluded in an image. Adding classes of meronymic information which provides meta-information (necessary for threat assessment) and allows for fast and accurate search an appropriate labeling of the ontology nodes is necessary. An active contour and morphological techniques will be applied to partition weapons and extract boundaries and convex hulls from their parts. Finite numerical sequences will be generated to label partonomic nodes. Visual and conceptual hierarchy trees will be derived from the firearm ontology's meronymy. The visual hierarchy tree is used for the purpose of weapon identification using their parts. The conceptual hierarchy will serve as meta-information depository. Links will be developed to transfer the search result from the visual to the conceptual hierarchy. The paper will report: the meronymic ontology along with its conceptual and visual hierarchies; experimental results on weapons partitioning and search.

9476-31, Session 7

Ramification algorithm for graphene sample-defect localization *(Invited Paper)*

Andre U. Sokolnikov, Visual Solutions and Applications (United States)

Recent development of a new 2D material graphene necessities sample characterization (in particular localization and distribution of defects). The presence of defects is unavoidable, however, it is possible to determine and predict defect distribution in graphene sample prior to the actual device making. A ramification algorithm is used for the above purpose.

9476-32, Session PTue

An estimation of distribution method for dynamic programming algorithm based on Copulas

Shuo Wang, Yiqun Zhang, China Aerospace Science & Industry Corp. (China); Zhiguo Wang, Beijing Institute of Electronic System Engineering (China)

Track-before-detect (TBD) based target detection involves hypothesis testing of merit functions which measure each track as a possible target track. Its accuracy depends on the precision of the distribution of merit functions, which determines the threshold for a test. Generally, merit functions are regarded Gaussian, and on this basis the distribution is estimated, which is true for most methods such as the multiple hypothesis tracking (MHT). However, merit functions for some other methods such as the dynamic programming algorithm (DPA) are non-Gaussian and cross-correlated. Since existing methods cannot reasonably measure the correlation, estimating the exact distribution remains difficult. If merit functions are assumed Gaussian and independent, the error between an actual distribution and its approximation may reach over 30 percent occasionally, and is divergent by propagation. Hence, in this paper, we propose a novel estimation of distribution method based on Copulas, by which the distribution can be estimated precisely, where the error is less than 1 percent without propagation. Moreover, the estimation merely depends on the form of merit functions and the structure of a tracking algorithm, and is invariant to measurements. Thus, the distribution can be

estimated in advance, greatly reducing the demand for real-time calculation of distribution functions.

9476-33, Session PTue

Fast algorithm of infrared small target detection in jitter background

Weiping Yang, Xinping Lu, Jicheng Li, National Univ. of Defense Technology (China); Zhilong Zhang, National Univ of Defense Technology (China)

In the high technical local battles, it is required that the weapon system have a fast reaction, a long target detection distance. Namely, the weapon system have to detect the target at a long distance in real-time. However, when the distance between the target and the weapon is long, the target image in infrared sensor is of a small size with only one or a few pixel's area while the interferences of noise and clutter background remain strong. Therefore, the detection of small targets with low signal-noise-ration (SNR) becomes a difficult task and a hot research field. In this paper, a fast algorithm is developed. After analyzing signal models of infrared small targets, noise and clutter, 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.

9476-34, Session PTue

Image feature extraction based multiple ant colonies cooperation

Zhilong Zhang, Weiping Yang, Jicheng Li, National Univ. of Defense Technology (China)

Feature extraction is a fundamental task in the field of remote sensing image analysis as well as image registration, target recognition and cloud recognition. A perfect feature extraction algorithm should be robust to image noise and clutter and extract meaningful image features.

Gradient magnitude is a basic image feature. Its excellent properties include high edge locating accuracy and low computational burden. But it is sensitive to noise and intensity change. However, phase congruency is immune to intensity change and noise, and sensitive to salient geometric feature in images.

This paper presents a novel image feature extraction algorithm based on multiple ant colonies cooperation. Firstly, a low resolution version of the input image is created using Gaussian pyramid algorithm, and two ant colonies are spread on the source image and low resolution image respectively. The ant colony on the low resolution image uses phase congruency as its inspiration information, while the ant colony on the source image uses gradient magnitude as its inspiration information. These two ant colonies cooperate to extract salient image features through sharing a same pheromone matrix. After the optimization process, image features are detected based on thresholding the pheromone matrix. Since gradient magnitude and phase congruency of the input image are used as inspiration information of the ant colonies, our algorithm shows higher intelligence and is capable of acquiring more complete and meaningful image features than other simpler edge detectors.

9476-35, Session PTue

Spherical Gaussian mixture model and object tracking system for PTZ camera

Hwangbo Seok, Chan-Su Lee, Yeungnam Univ. (Korea, Republic of)

Recently, pan-tilt-zoom(PTZ) camera is widely used in extensive-area surveillance applications. A number of background modeling methods have been proposed within existing object detection and tracking systems. However, conventional background modeling methods for PTZ camera have difficulties in covering extensive field of view(FOV). This paper presents a novel object tracking system based on a spherical background model for PTZ camera. The proposed system has two components: The first one is the spherical Gaussian mixture model(S-GMM) that learns background for all the view angles in the PTZ camera. Also, Gaussian parameters in each pixel in the S-GMM are learned and updated. The second one is object tracking system with foreground detection using the S-GMM in real-time. The S-GMM is generated off-line from projection to a spherical coordinate for the c! aptured image at fixed offset pan-tilt angle. The spherical coordinate is estimated from the known pan-tilt angle of the PTZ camera and image size by assuming that the center line of sight passes the middle of the captured image and the corner of the rectangle of the image is contacted to the virtual spherical coordinate with radius R. By updating the Gaussian components which are the weight, mean and covariance of the generated spherical background model, the S-GMM classifies foreground area from the background model in real-time. At the same time, moving object is detected and is tracked based on extended Kalman filter(EKF). Finally, we estima! te and analyze the target's trajectory from the estimated center of the foreground area. The proposed system is suitable to cover wide FOV and is able to exactly track moving objects. We demonstrate the advantages of the proposed S-GMM for object tracking system using PTZ camera. Also, we expect to build a more advanced surveillance applications via the proposed system.

9476-36, Session PTue

BMVT-M based IR ground target detection

Yun-Ji Lim, Sungho Kim, Yeungnam Univ. (Korea, Republic of); Yoeongrae Jo, Ujin Song, POSTECH (Korea, Republic of); Sohyun Kim, ADD (Korea, Republic of)

Target detection is one of the key technologies in military applications and infrared (IR) sensors are frequently used for small target detection. However, IR sensor has limitations of passive sensor such as low detection capability to weather and atmospheric effects. In recent years, sensor fusion is active research topic to overcome the limitations. We choose additional active SAR sensor for sensor fusion because SAR sensor is robust to various weather conditions.

Boolean Map visual theory based target detection method (BMVT) is the state-of-the-art method of small IR target detection. Conventional BMVT has good performance in clear environment such as sky and sea background for small target. However, it shows poor performance when the target has extended size or the target is located in complex background such as ground-background with a lot of clutters. Therefore, we presents an improved ground target detection method based on the BMVT and Morphology filter (BMVT-M). The proposed algorithm consists of two parts: The first part is target enhancement based on the BMVT. The second part is clutter rejection and target enhancement based on the Morphology filter. In addition, conventional BMVT is not suitable to SAR image for target detection because SAR image has so many of shot noise. Therefore we apply median filter before the BMVT in SAR image to suppress shot noise. According to the BMVT, multiple feature channels can be fused by set operations such as AND, OR and NOT. This means that it is possible to produce a variety of features from a set of basic features. In addition, we can fuse various sensors features using the algorithm. For the verification of the performance, experiments performed in various cluttered backgrounds, such as ground, sea, sky generated by the OKTAL-SE tool. The proposed algorithm showed upgraded detection performance than conventional method in most of cases in terms of detection rate and false alarm rate. Moreover, we discuss the applicability of the proposed method to the SAR and IR sensor fusion research.

9476-37, Session 8

Metal-organic hybrid metamaterial THz imaging detectors etching, dramitically increasing the speed and lowering the cost of production of such FPAs *(Invited Paper)*

Dragoslav Grbovic, Fabio Alves, Gamani Karunasiri, Naval Postgraduate School (United States)

We investigate the feasibility of using SU-8 negative photoresist as a structural material in metal-organic hybrid THz imaging detectors. We will discuss characterization of metal-organic hybrid metamaterials for MEMS-based terahertz (THz) thermal sensors and design and microfabrication process for building SU8-based MEMS THz focal plane arrays. Metamaterials of this kind, exhibiting absorption properties comparable to those of resonant metamaterials made using traditional thin films, coupled with the applicability of SU-8 as a structural material, offers possibilities for quick, simple microfabrication of focal plane arrays of THz imaging detectors. SU-8 is a low-cost material that can quickly be spun onto a substrate at a wide range of thicknesses and photolithographically patterned into a variety of structures. This removes the need for both PECVD deposition and plasma.

9476-38, Session 8

THz devices based on 2D electron systems *(Invited Paper)*

Huili Grace Xing, Univ. of Notre Dame (United States)

In two-dimensional electron systems with a mobility on the order of 1,000 – 10,000 cm2/Vs, the electron scattering time is about 1 ps. For the THz window of 0.3 – 3 THz, the THz photon energy is in the neighborhood of 1 meV, substantially smaller than the optical phonon energy of solids where these 2D electron systems resides. These properties make the 2D electron systems interesting as a platform to realize THz devices. In this talk, I will review 3 approaches investigated in the past few years in my group toward THz devices. The first approach is the conventional high electron mobility transistor based on GaN toward THz amplifiers. The second approach is to employ the tunable intraband absorption in 2D electron systems to realize THz modulators, where I will use graphene as a model material system. The third approach is to exploit plasma wave in these 2D electron systems that can be coupled with a negative differential conductance element for THz amplifiers/sources/detectors.

9476-39, Session 8

Graphene active plasmionics for terahertz device applications *(Invited Paper)*

Taiichi T Otsuji, Research Inst. of Electrical Communication, Tohoku Univ. (Japan); Alexander Dubinov, Inst. for Physics of Microstructures, RAS; Lobachevsky State Univ. of Nizhny Novgorod (Russian Federation); Maxim Ryzhii, Complex Systems Modeling Laboratory, University of Aizu (Japan); Stephane Boubanga Tombet, Tohoku Univ. (Japan) and Research Inst. of Electrical Communication, Tohoku Univ. (Japan); Akira Satou, Research Inst. of Electrical Communication, Tohoku Univ. (Japan); Vladimir Mitin, Dept. of EE, University at Buffalo, State University of New York (United States); Michael S Shur, Rensselaer Polytechnic Institute (United States)

This paper reviews recent advances in graphene plasmonic heterostructures for terahertz (THz) device applications. A double graphene-layer (DGL) core-shell structure with a thin tunnel barrier layer is sandwiched between the outer gate stack layers at both sides. When the band offset is aligned to the THz photon energy, the DGL structure can mediate photon-assisted resonant tunneling, resulting in resonant emission or detection of the THz radiation. The cooperative double-resonant excitation with structure-sensitive graphene plasmons gives rise to various functionalities in the THz device implementations.

9476-40, Session 8

Terahertz nonlinear optics of graphene and 3D topological insulators *(Invited Paper)*

Alexey A. Belyanin, Texas A&M Univ. (United States); Xianghan Yao, Mikhail D. Tokman, Institute of Applied Physics (Russian Federation)

Recently there has been a surge of interest in emergent 2D materials with chiral symmetry andgapless linear spectrum of free carriers near the Dirac point where the energy bands form a cone in the momentum space. Most notable examples include graphene and surface states in 3D topological insulators such as Bi2Se3 and Bi2Te3. So far the main effort was directed at studying their topological properties and carrier transport. In this talk we show that the systems with massless Dirac electrons possess a giant mid/far-infrared optical nonlinearity, perhaps the highest among known materials. Both third-order and second-order nonlinear responses are possible. Although graphene is an isotropic medium for low-energy electron excitations, the second-order nonlinear susceptibility becomes non-zero when its spatial dispersion is taken into account. In this case the anisotropy is induced by the in-plane wave vectors of obliquely incident or in-plane propagating electromagnetic waves. The nonlinear response can be enhanced by applying a magnetic field or coupling to surface plasmons. The dispersion curves of surface plasmons supported by a massless Dirac fermion layer stronglydeviate from the photon dispersion already at THz frequencies, leading to a tight vertical confinement and large in-plane wave vector which can be matched to the sum of the photon wave vectors at mid- or even near-IR frequencies. This enables phase-matched difference-frequency generation (DFG) of THz plasmons with counter-propagating pump fields. The DFG process can reach efficiencies of 0.1 W/W2 and is broadly tunable by gating or varying an angle of incidence. Strong optical nonlinearity of materials with massless Dirac fermions enables efficient generation of coherent THz radiation, generation of entangled photon states, and control of electron quantum states by means of nonlinear optics.

9476-41, Session 8

Electronics above 100 GHz *(Invited Paper)*

William D. Palmer, Microsystem Technology Office (United States)

The US Department of Defense Research and Engineering Enterprise funds leading-edge research to continually expand the boundaries of human capability. Over the past several years there has been an increasing level of research focused on the sub-millimeter wave or THz region of the electromagnetic spectrum, typically defined as 300 GHz to 3,000 GHz. As solid-state electronics approach this range from lower frequencies, device scaling, carrier mobility, and parasitics severely limit performance. From higher frequencies, the output power and efficiency of quantum-cascade lasers and sources based on optical mixing drop off dramatically. These issues create the well-known “THz gap” where signal generation and amplification technology is lacking. A number of recent US DoD research programs have created vacuum electronic and solid-state devices capable of closing the THz gap. This talk will place these research programs in context, describe the program goals, and highlight selected breakthroughs.

9476-42, Session 8

Toward low-loss, infrared and THz nanophotonics and metamaterials: surface photon polariton modes in polar dielectric crystals *(Invited Paper)*

Joshua D. Caldwell, U.S. Naval Research Lab. (United States)

The field of nanophotonics is based on the ability to confine light to sub-diffractional dimensions. Up until recently, research in this field has been primarily focused on the use of plasmonic metals. However, the high optical losses inherent in such metal-based surface plasmon materials has led to an ever-expanding effort to identify, low-loss alternative materials capable of supporting sub-diffractional confinement. One highly promising alternative are polar dielectric crystals whereby sub-diffraction confinement of light can be achieved through the stimulation of surface phonon polaritons within an all-dielectric, and thus low loss material system. Both SiC and hexagonal BN are two exemplary SPhP systems, which along with a whole host of alternative materials promise to transform nanophotonics and metamaterials in the mid-IR to THz spectral range. In addition to the lower losses, these materials offer novel opportunities not available with traditional plasmonics, for instance hyperbolic optical behavior in natural materials such as hBN, enabling super-resolution imaging without the need for complex fabrication. This talk will provide an overview of the SPhP phenomenon, a discussion of what makes a 'good' SPhP material and recent results from SiC and the naturally hyperbolic material, hBN from our research group.

9476-43, Session 8

Terahertz science and technology of carbon nanomaterials *(Invited Paper)*

Junichiro Kono, Rice Univ. (United States)

The field of nanophotonics is based on the ability to confine light to sub-diffractional dimensions. Up until recently, research in this field has been primarily focused on the use of plasmonic metals. However, the high optical losses inherent in such metal-based surface plasmon materials has led to an ever-expanding effort to identify, low-loss alternative materials capable of supporting sub-diffractional confinement. One highly promising alternative are polar dielectric crystals whereby sub-diffraction confinement of light can be achieved through the stimulation of surface phonon polaritons within an all-dielectric, and thus low loss material system. Both SiC and hexagonal BN are two exemplary SPhP systems, which along with a whole host of alternative materials promise to transform nanophotonics and metamaterials in the mid-IR to THz spectral range. In addition to the lower losses, these materials offer novel opportunities not available with traditional plasmonics, for instance hyperbolic optical behavior in natural materials such as hBN, enabling super-resolution imaging without the need for complex fabrication. This talk will provide an overview of the SPhP phenomenon, a discussion of what makes a 'good' SPhP material and recent results from SiC and the naturally hyperbolic material, hBN from our research group.

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9477-1, Session 1

Holographic 3D tracking of microscopic tools *(Invited Paper)*

Jesper Glückstad, Mark Villangca, Andrew Bañas, Darwin Palima, Technical Univ. of Denmark (Denmark)

Recently, we pioneered the concept of free-floating waveguides that can be optically trapped and "remote-controlled" in a volume, hence coined Wave-guided Optical Waveguides (WOWs). To be exploring the full potential of this new structure-mediated approach in challenging microscopic geometries requires a versatile 3D light coupling that can dynamically track a plurality of WOWs to ensure continuous optimal light coupling on the fly. We have integrated computer generated holography to maintain high light throughput for the WOWs, so that we can dynamically control the 3D focus position of the coupling beams. Our results show that we can simultaneously maneuver the WOWs in 3D space while dynamically coupling light through them. The design possibilities offered by 3D-printed WOWs, the augmented holographic light coupling combined with the advanced 3D micromanipulation opens the possibility for performing exciting precision engineered light-matter interaction where it is needed.

9477-2, Session 1

Efficient live face detection to counter spoof attack in face recognition systems *(Invited Paper)*

Bikram K. Biswas, Mohammad S. Alam, Univ. of South Alabama (United States)

Face recognition is used as an effective biometrics tool in almost all major modern security systems. However, the recognition, authentication and liveness detection of the face of an actual user is a major challenge because any imposter or a non-live face of the actual user can spoof the security system. In this research, we propose a robust technique which detects liveness of faces to counter a spoof attack using a three-dimensional fast Fourier transform based technique. The proposed technique compares average energies of live face sequences and fake face sequences from their recorded videos by evaluating energies of selective high frequency bands of average power spectrum of both live and non-live faces. To do this, average energy spectrums should be multiplied by a bandpass filter. Bandpass filter will eliminate low frequency components. The rest of the spectrum will be divided into some circular bands. Energies of those circular bands will be calculated thereafter. The difference of energies in those bands will differentiate live faces from fake faces. Various types of fake faces will be tested in this research. It also carries out proper recognition and authentication of the face of actual user using the fringe-adjusted joint transform correlation technique. Experimental results show that the proposed technique effectively identifies the live faces, thus preventing spoof attacks.

9477-3, Session 1

Recent results of a medium wave infrared compressive imaging sensor *(Invited Paper)*

Richard Shilling, Robert R. Muise, Lockheed Martin Missiles and Fire Control (United States)

Recent imaging results of a prototype medium wave infra-red (MWIR) compressive imaging sensor are presented. We experimentally confirm that information at high spatial resolution can be successfully recovered from measurements made with a small FPA beyond its own native resolution. Based on our previous work, we address the issues of signal loss, pose estimation between the image planes of the spatial light modulator (SLM) and FPA, modeling of compressive codes subject to the sensor, and post-processing techniques for removal of reconstruction artifacts. We experiment with the variable acuity super-pixeling feature on the FPA that lends itself well to compressive imaging. We further describe the design of compressive codes applied for target detection using adaptive techniques based on orthogonal matching pursuit and give initial results.

9477-4, Session 1

Advanced big data research through measurements and multi-stakeholder evaluations *(Invited Paper)*

Ashit Talukder, National Institute of Standards and Technology (United States)

No Abstract Available

9477-5, Session 2

Comparison of spatial domain optimal trade-off maximum average correlation height (OT-MACH) filter with scale invariant feature transform (SIFT) using images with poor contrast and large illumination gradient *(Invited Paper)*

Akber A. Gardezi, COMSATS Institute of Information Technology (Pakistan) and Univ. of Sussex (United Kingdom); Tabassum-Ur-Razaq Qureshi, Ahmad T. Alkandri, Rupert Young, Philip Birch, Christopher Chatwin, Univ. of Sussex (United Kingdom)

A spatial domain optimal trade-off Maximum Average Correlation Height (OT-MACH) filter has been previously developed and shown to have advantages over frequency domain implementations in that it can be made locally adaptive to spatial variations in the input image background clutter and normalised for local intensity changes. In this paper we compare the performance of the spatial domain (SPOT-MACH) filter to the widely applied data driven technique known as the Scale Invariant Feature Transform (SIFT). The SPOT-MACH filter is shown to provide more robust recognition performance than the SIFT technique for demanding images such as poor contrast thermal imagery and images in which there are large illumination gradients. The SIFT method depends on reliable local edge-based feature detection over large regions of the image plane which is compromised in some of the demanding images we examined for this work. The disadvantage of the SPOT-MACH filter is its numerically intensive nature since it is template based and is implemented in the spatial domain. Thus efficient hardware configurations are also briefly considered that would allow effective real-time implementation of the SPOT-MACH filter.

9477-6, Session 2

A robust fringe-adjusted joint transform correlator for efficient object detection

Paheding Sidike, Vijayan K. Asari, Univ. of Dayton (United States); Mohammad S. Alam, Univ. of South Alabama (United States)

The fringe-adjusted joint transform correlation (FJTC) technique has been widely used for real-time optical pattern recognition applications. However, the classical FJTC technique suffers from distortions due to noise, scale, rotation and illumination variations of the targets in the input scene. Several improvements of the FJTC have been proposed in the literature to accommodate these problems. Some popular techniques such as synthetic discriminant function (SDF) based FJTC was designed to alleviate the problems of scale and rotation variations of the target, while wavelet based FJTC has been found to yield better performance for noisy targets in the input scenes. While these techniques integrated with specific features to improve performance of the FJTC, a unified and synergistic approach to equip the FJTC with robust features is yet to be done. Consequently, in this paper, a robust FJTC technique based on sequential filtering approach is proposed. The proposed method is constructed in such a way that it is insensitive to rotation, scale, noise and illumination variations of the targets. Specifically, local phase (LP) features of monogenic signal is utilized to reduce the effect of background illumination thereby achieving illumination invariance. The SDF is implemented to achieve rotation and scale invariance, whereas the logarithmic fringe-adjusted filter (LFAF) is employed to reduce the noise effect. The proposed technique can be used as a real-time region-of-interest detector in wide-area surveillance for automatic object detection. The feasibility of the proposed technique has been tested on a set of aerial data and has observed promising performance in detection accuracy.

9477-7, Session 2

Human detection in sensitive security areas through recognition of omega shapes using MACH filters

Saad Rehman, Farhan Riaz, Ali Hassan, Muwahida Liaquat, National Univ. of Sciences and Technology (Pakistan); Rupert Young, Univ. of Sussex (United Kingdom)

Crowd detection has gained a considerable importance for use in aggravated security scenarios over recent times. An effective security application relies strongly on detailed information regarding the scene under consideration. A larger accumulation of humans than the number of personal authorized to visit a security controlled area must be effectively detected, amicably alarmed and immediately monitored. A framework involving a novel combination of some well-known techniques enables an immediate detection of a crowd in a region under observation. The Canny edge detector provides robust sets of edges in real-time from frames grabbed by a camera. Hysteresis thresholding removes unnecessary information in the image and delivers only the edge map of objects requiring attention. These edges can be conveniently translated into number of closed shapes present in the scene. Training of advanced correlation pattern recognition based filters, such as the E-MACH filter, on desired shapes such as elliptical representations of human faces yields effective detections. The inherent ability of advanced correlation pattern recognition filters caters for angular rotations in the target object and allows a decision regarding the existence of number of faces exceeding an allowed figure in the monitored area. Examples are presented to demonstrate the effectiveness of the technique in monitoring crowds of people in restricted scenarios.

9477-9, Session 3

Simulation of pattern and defect detection in periodic amplitude and phase structures using photorefractive four-wave mixing

Georges T. Nehmetallah, The Catholic Univ. of America (United States); Partha P. Banerjee, Univ. of Dayton (United States); Jed Khoury, Air Force Research Lab. (United States)

The nonlinearity inherent in four-wave mixing in photorefractive (PR) materials is used for adaptive filtering. Examples include script enhancement on a periodic pattern, scratch and defect cluster enhancement, periodic pattern dislocation enhancement, etc. through intensity filtering image manipulation. Organic PR materials have large space-bandwidth product, which makes them useful in adaptive filtering techniques in quality control systems. For instance, in the case of edge enhancement, phase conjugation via four-wave mixing suppresses the low spatial frequencies of the Fourier spectrum of an aperiodic image and consequently leads to image edge enhancement.

In this work, we model, numerically verify, and simulate the performance of a four wave mixing setup used for edge, defect and pattern detection in a periodic amplitude and phase structures. The results show that this technique successfully detects the slightest defects clearly even with no enhancement. This technique should facilitate improvements in applications such as image display sharpness utilizing edge enhancement, production line defect inspection of fabrics, textiles, e-beam lithography masks, surface inspection, and materials characterization.

9477-10, Session 3

Efficient thermal image segmentation through integration of nonlinear enhancement with unsupervised active contour model

Fatema A. Albalooshi, Evan Krieger, Paheding Sidike, Vijayan K. Asari, Univ. of Dayton (United States)

Thermal images have been exploited in many areas of pattern recognition applications. Infrared thermal image segmentation can be used for object detection by extracting regions of abnormal temperature from the image. However, lacking of texture and color information, and introducing blurring effect of the thermal image, segmenting infrared heat pattern has become a challenging task. Furthermore, many segmentation methods used in visible images may not be suitable for thermal imagery mainly due to its dissimilar intensity distribution compared to visual images. In this paper, a new method is proposed to improve the performance of image segmentation in thermal imagery. The proposed scheme efficiently fuses nonlinear intensity enhancement and Unsupervised Active Contour Models (UACM) to generate robust object region and boundary extraction in thermal imagery. The nonlinear intensity enhancement improves visual quality by combining dynamic range compression and contrast enhancement in thermal imagery, while the UACM incorporates active contour evolutional function and artificial neural networks. The nonlinear image enhancement technique allows enriched image features to be utilized by UACM to automatically direct evolutional contour towards the region of interest, and thus improves segmentation process. The algorithm is tested on segmentation of different objects in real world thermal images and it is observed that the nonlinear enhancement has significantly improved the segmentation performance. The evaluation is done by comparing the segmentation results with the ground truth. In addition, we integrate the UACM with some common image enhancement techniques to find the most effective combination in the segmentation process.

9477-11, Session 3

An improved algorithm for pedestrian detection

Amr Yousef, Univ. of Business and Technology (Saudi Arabia); Prakash Duraisamy, Rochester Institute of Technology (United States); Mohammad Ataul Karim, Univ. of Massachusetts Dartmouth (United States)

In this paper we present a technique to detect pedestrians surveillance video cams. Histogram of gradients (HOG) and Haar wavelets with the aid of support vector machines (SVM) and AdaBoost classifiers show good identification performance on different objects classification including pedestrians. We propose a new shape descriptor derived from the intra-relations between gradient orientations in a way similar to the HOG. The proposed descriptor is a two 2-D grid of orientation connections measured at different offsets. The gradient magnitudes and offsets derived from a sliding window with different scales and sizes are used to construct two 2-D symmetric grids with their horizontal and vertical vertices are the quantized orientation values. The first grid identifies the repetition of the different orientation pairs for a given offset while the second gird measures the percentage of magnitudes for the corresponding pairs. Since the resultant matrices will be symmetric, the feature vector is formed by concatenating the upper diagonal grid coefficients collected in a raster way. The training and testing data are collected from the video cam feeds in Hampton roads area, United States. Classification is done using SVM classifier with radial basis kernel. Experimental results show improved performance compared to the current state-of-art techniques.

9477-12, Session 4

Gaussian-weighted neighborhood connectivity of nonlinear line attractor for learning complex manifolds

Theus Aspiras, Univ. of Dayton (United States); Wesam A. Sakla, Air Force Research Lab. (United States); Vijayan K. Asari, Univ. of Dayton (United States)

The human brain has the capability to process high quantities of data quickly for detection and recognition tasks. These tasks are made simpler by the understanding of data, which intentionally removes redundancies found in higher dimensional data and maps the data onto a lower dimensional space. The brain then encodes manifolds created in these spaces, which reveal a specific state of the system. We propose to use a recurrent neural network, the nonlinear line attractor (NLA) network, for the encoding of these manifolds as specific states, which will draw untrained data towards one of the specific states that the NLA network has encoded. We propose a Gaussian-weighted modular architecture for reducing the computational complexity of the conventional NLA network. The proposed architecture uses a neighborhood approach for establishing the interconnectivity of neurons to obtain the manifolds. The modified NLA network has been implemented and tested on the Electro-Optic Synthetic Vehicle Model Database created by the Air Force Research Laboratory (AFRL), which contains a vast array of high resolution imagery with several different lighting conditions and camera views. It is observed that the NLA network has the capability for representing high dimensional data for the recognition of the objects of interest through its new learning strategy. A nonlinear dimensionality reduction scheme based on kernel discriminant analysis has found to be very effective in providing a low dimensional representation of the dataset. Application of the modified NLA algorithm on this reduced dimensional space would provide fast and more accurate recognition performance for real time applications.

9477-13, Session 4

Volume component analysis for classification of LiDAR data

Nina M. Varney, Vijayan K. Asari, Univ. of Dayton (United States)

LiDAR data is a set of geo-spatially located points that contain X, Y, and Z location data. Currently, most LiDAR feature extraction relies on geometrical features specific to the point cloud of interest. These geometrical features are scene-specific, and often rely on the scale and orientation of the object for classification. This paper proposes a robust method for reduced dimensionality feature extraction of three-dimensional (3-D) objects using a volume component analysis (VCA) approach.

The proposed VCA approach is based on principle component analysis (PCA) in a 3-dimesional perspective. PCA is a feature extraction method that computes a covariance matrix from the original input vectors. The eigenvectors corresponding to the largest eigenvalues of the covariance matrix are used to describe an image. Block-based PCA is an adapted method for feature extraction in facial images because PCA, when performed in local areas of the image, can extract more significant features than can be extracted when an entire image is considered. The image space is split into several of these blocks, and PCA is computed individually for each block.

The LiDAR point cloud can be represented as a series of voxels whose values correspond to the point density within that relative location. From this voxelized space, block-based PCA is used to analyze sections of the space where the sections, when combined, will represent features of the entire 3-D object. These features are then used as the input to a multi-class support vector machine which is trained to identify five classes of objects such as ground, vegetation, vehicles, buildings and barriers with an overall accuracy of 95.06%.

9477-14, Session 4

Machine vision for airport runway identification

Matt Schubert, Andrew J. Moore, Chester Dolph, Glenn Woodell, NASA Langley Research Ctr. (United States)

For rigid objects and fixed scenes, current machine vision technology is capable of identifying imagery rapidly and with specificity over a modest range of camera viewpoints and scene illumination. We applied that capability to the problem of runway identification using video of sixteen runway approaches at nine locations, subject to two simplifying assumptions. First, by using approach video from just one of the several possible seasonal variations (no snow cover and full foliage), we artificially removed one source of scene variation in this study. Secondly, by not using approach video at dawn and dusk, we limited the study to two illumination variants (day and night). We did allow scene variation due to atmospheric turbidity by using approach video from rainy and foggy days in some daytime approaches. With suitable ensemble statistics to account for temporal continuity in video, we observed high location specificity (>90% Bayesian posterior probability). We also tested repeatability, i.e., identification of a given runway across multiple videos, and observed robust repeatability only if illumination (day vs. night) was the same and approach visibility was good. Both specificity and repeatability degraded in poor weather conditions. The results of this simplified study show that geolocation via real-time comparison of cockpit image sensor video to a database of runway approach imagery is feasible, as long as the database contains imagery from the same time of day and the weather is clear at the time of the flight.

9477-15, Session 4

Road sign recognition using Viapix module and correlation

Yousri Ouerhani, ISEN Brest (France) and ACTRIS (France); M. Desthieux, ACTRIS (France); Ayman Alfalou, ISEN Brest (France)

In this paper, we propose an optimized approach for the road sign recognition and identification. The proposed approach consists in using panoramic images provided by the device, VIAPIX [1], developed by our company ACTRIS [2]. Besides, we have used the correlation technique for the road sign recognition in images.

Currently used by road engineering companies and road managers, VIAPIX® enables to reference, inventory and measure road assets in order to produce data for GIS (Geographic Information System). Composed of an innovative acquisition device and a powerful processing software, VIAPIX® is the essential solution for road network management. Using the three cameras which composed the acquisition device, VIAPIX provides panoramic images with an angle of view of 180°.

The proposed approach consists in using these panoramic images in order to identify all road signs existing in these images. To do so, on the one hand, we propose to use correlation technique based on adaptative filters. In fact, all objects with the same features as road signs are detected [3]. Then, the VLC correlation technique is applied to these objects using filters manufactured from reference images in an offline way. These filters are adapted to the size of detected objects.

On the other hand, in order to reduce computing time, we propose to reduce the number of correlations to realize for each detected object. In fact, correlation is done using only filters manufactured from reference images with the same features as the detected object (shape and color) [4].

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9477-16, Session 4

Fourier transform-based method for pattern matching: affine invariance and beyond

Madhuri Gundam, Dimitrios Charalampidis, Univ. of New Orleans (United States)

Several pattern matching techniques have focused on affine invariant pattern matching, mainly because rotation, scale, translation, and shear are common image transformations. However, transformations in addition to affine ones are also common. Such transformations may be approximated as a small deformation on top of an affine transformation. In order to achieve this goal, we propose an improved Fourier Transform (FT)-based pattern matching technique. The spatial domain image consisting of the pattern is first decomposed into concentric circular rings, which are centered in middle of the image. Next, the FT of each ring is computed. Apparently, adding the individual complex-valued FT essentially provides the FT of the original image. Past techniques used the FT to identify the parameters of the affine transformation between two patterns. However, assuming that the rings can be rotated with respect to each other, parameters of transformations beyond the affine ones can be computed. The proposed technique achieves this objective using dynamic programming, starting from the FT associated with the smallest ring and moving outwards to the FT of the largest ring. The objective is to find the two paths corresponding to the two largest sums of FT magnitudes computed from the individual FTs, and therefore, the directional properties of the two patterns. The intuition behind this approach is that since the rings are not necessarily aligned in the same manner for the two patterns, their ring FTs may also be rotated with respect to each other. Simulations illustrate the effectiveness of the proposed technique.

9477-17, Session 4

An empirical comparison of K-SVD and GMRA for dictionary learning

Vipin Vijayan, Univ. of Notre Dame (United States); Wesam A. Sakla, Air Force Research Lab. (United States)

The field of dictionary learning has gained much attention over the past decade. The K-SVD algorithm is a dictionary learning algorithm based on work from the compressive sensing field and uses sparsity-based optimization techniques. Geometric multi-resolution analysis (GMRA) is a multi-scale technique that is based on work from the applied mathematics field and is used for manifold approximation of high-dimensional data. GMRA partitions the data into a tree structure and then estimates affine subspaces in every node of the tree using SVDs. In this work, we compare the ability of these fundamentally different approaches to learn dictionaries and reconstruct images using the same number of coefficients.

These algorithms have been comparatively evaluated on vehicle images from the Electro-Optic Synthetic Vehicle Model Database created by the Air Force Research Laboratory (AFRL), which contains a vast array of high resolution imagery with variable lighting conditions and camera views. Extensive experiments were conducted on training and testing partitions of the imagery to sweep through the relevant parameters of both dictionary learning algorithms and record the RMS error as a function of the dictionary coefficients used to reconstruct the images. Preliminary conclusions reveal that the GMRA technique tends to outperform the K-SVD technique on training data, while the K-SVD technique may generalize better by providing lower reconstruction error on test data.

9477-18, Session 5

Numerical implementation of the multiple image optical compression and encryption technique

Yousri Ouerhani, ACTRIS (France) and ISEN Brest (France); Mohammed R. Aldossari, Ayman Alfalou, ISEN Brest (France); Christian Brosseau, Univ. de Bretagne Occidentale (France)

We propose an optimized encryption level applied to our multiple-image compression and encryption method. First, we introduce a double optimization procedure for spectrally multiplexing multiple images. This technique is adapted, for a numerical implementation, from a recently proposed optical setup implementing the Fourier transform (FT) [1]. The new analysis technique is a combination of spectral fusion based on the properties of FT, specific spectral filtering, and quantization of the remaining encoded frequencies using an optimal number of bits. The spectral plane (containing the information to send and/or to store) is decomposed in several independent areas which are assigned according a specific way. In addition, each spectrum is shifted in order to minimize their overlap. The dual purpose of these operations is to optimize the spectral plane allowing us to keep the low- and high-frequency information (compression) and to introduce an additional noise for reconstructing the images (encryption). Our results show that not only can the control of the spectral plane enhance the number of spectra to be merged, but also that a compromise between the compression rate and the quality of the reconstructed images can

be tuned. Spectrally multiplexing multiple images defines a first level of encryption. A second level of encryption based on a real key image is used to reinforce encryption. Firstly, we shall be concerned with optimizing the compression rate by adapting the size of the spectral block to each target image and decreasing the number of bits required to encode each block. This size adaptation is realized by means of the root-mean-square (RMS) time-frequency criterion [2]. We have found that this size adaptation provides a good tradeoff between bandwidth of spectral plane and number of reconstructed output images [3]. Secondly, the encryption rate is improved by using a real biometric key and randomly changing the rotation angle of each block before spectral fusion. A numerical implementation of this method using two numerical devices (CPU and GPU) is presented [4].

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9477-19, Session 5

Night time monitoring using registration of RGB cameras and infrared cameras

Prakash Duraisamy, Rochester Institute of Technology (United States); Amr Hussein Yousef, Univ. of Business and Technology (Saudi Arabia); Mohammad Ataul Karim, Univ. of Massachusetts Dartmouth (United States)

Monitoring open areas at night time is a challenging task. It requires a lot of human intervention and is a tedious task. In this paper, we introduce a novel technique (based on the techniques we have developed in another context) by registering infrared camera information with day time RGB camera information. This algorithm will be useful for monitoring open areas without much human interaction, under poor illumination and within a short time period.

9477-21, Session 5

Adaptive threshold and error-correction coding for robust data retrieval in optical media

Thomas T. Lu, Jet Propulsion Lab. (United States); Colin Costello, California State Polytechnic Univ., Pomona (United States); Matthew Ginley-Hidinger, Occidental College (United States); Tien-Hsin Chao, Jet Propulsion Lab. (United States)

No Abstract Available

9477-22, Session 6

Alignment-free all solid state multiplexed holographic memory systems and applications *(Invited Paper)*

Stuart Yin, The Pennsylvania State Univ. (United States); Claire Luo, General Opto Solutions, LLC (United States)

In this paper, an alignment-free all solid state angularly multiplexed holographic memory system is presented, in which the beam scanning device and angularly multiplexed holograms are integrated into the same piece of KTN crystal. It offers the advantages of both fast access speed (on the order of microsecond) and free of alignment. The applications of this unique holographic memory systems to automatic target recognition as well as real time 3-dimensional imaging and display are also discussed.

9477-23, Session 6

Holographic content addressable storage

Tien-Hsin Chao, Thomas T. Lu, George F. Reyes, Jet Propulsion Lab. (United States)

No Abstract Available

9477-28, Session 6

Detection of weak edges using image registration

Prakash Duraisamy, Rochester Institute of Technology (United States); Amr Hussein Yousef, Univ. of Business and Technology (Saudi Arabia); Shagan Sah, Rochester Institute of Technology (United States); Steve Jackson, Xiaohui Yuan, Univ. of North Texas (United States)

Edge detection is an important tool in 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 illumination and fail under poor illumination, i.e., weak edges. This paper focuses on extracting weak edges. We detected the weak edges by using image registration algorithm. Images which depict different views of weak edges are registered using camera matrix. The registered view reinforce the weak edges. Experiments on a different weak edge images show that the our algorithm can actually overcome the drawbacks of traditional edge detection algorithm.

9477-30, Session 6

Real-time holographic heterodyne spatial filtering

Jed Khoury, Lartec, Inc. (United States)

Traditionally, homodyne and heterodyne are a combination of a frequency mixer followed by a low-pass filter. Mixing two signals of frequencies f1 and f2, generates signals of frequencies f1 + f2 and f1- f2 and their integer multiples. Both multiplication heterodyne and phase sensitive detection have been demonstrated optically by using photorefractive, four-wave mixing (FWM). The multiplicative characteristic of FWM was used for mixing, and the response time of the photorefractive medium is used for low-pass filtering. If one of the input beams is both spatially and temporally modulated using wobble rotating mirror, depends on which mode is heterodyned, one can generates orthogonal set of Bessel band pass filters.

This scheme can be integrated part within parallel data acquisition systems for applications involved nondestructive testing.

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9477-26, Session PSThu

Pose estimation of non-cooperative targets without feature tracking

Jie Liu, Huazhong Univ. of Science and Technology (China); Zongming Liu, Shan Lu, Shanghai Key Lab. of Aerospace Intelligent Control Technology (China) and Shanghai Academy of Space Flight Technology (China); Nong Sang, Huazhong Univ. of Science and Technology (China)

Pose estimation is playing the vital role in the final approach phase of two spacecraft, one is the target spacecraft and the other one is the observation spacecraft. Traditional techniques are usually based on feature tracking, which will not work when sufficient features are unavailable. To deal with this problem, we present a stereo camera-based pose estimation method without feature tracking. First, stereovision is used to reconstruct 2.5D of the target spacecraft and a 3D reconstruction is presented by merged all the point cloud of each viewpoint. Then a target-coordinate system is built using the reconstruction result. Finally, point cloud registration algorithm is used to solve the current pose between the observation spacecraft and the target spacecraft in real time. Experimental results show that both the position errors and the attitude errors satisfy the requirements of pose estimation. The method provides a new solution for pose estimation without knowing the information of the target and this algorithm is with wider application range compared with the other algorithms based on feature tracking

9477-27, Session PSThu

Pose estimation of non-cooperative targets based on docking surface

Wenkai Du, Huazhong Univ. of Science and Technology (China); Zongming Liu, Yu Zhang, Shuqing Cao, Shanghai Academy of Space Flight Technology (China); Nong Sang, Huazhong Univ. of Science and Technology (China)

In space rendezvous and docking missions, pose estimation of non-cooperative targets is challenging as priori information about motion and structure are unknown. The extraction and recognition are far more difficult conducted on a whole target. The docking surfaces of the target have more sophisticated structure with similar appearance among different countries than other surfaces. So docking surface is easy to automatically recognize or manually mark in images. In this paper, the mentioned problem is solved by using only visual sensors. Using two cameras mounted on a chaser satellite, when the docking surface is in the visual field, 3-D coordinates of the four vertices can be calculated with the stereoscopic vision method. Coordinate system is established on the docking surface to describe the pose of the target. Firstly, a novel framework is proposed to detect edges of the docking surface in each image. Specifically, we detect lines in an image and group them according to the slopes. A control point representing mark information is utilized to pick out the edges from the lines detected. Then, the pose of the target is calculated by the four vertices of the docking surface. Simulation result shows that the position errors and attitude errors meet the requirement of pose estimation. The method provides a new solution for pose estimation of the non-cooperative target, and has potential significance for space rendezvous and docking technology.

9477-29, Session PSThu

Invariant correlation filters with peak stability parameter in problem of scaled objects recognition

Petr A. Ivanov, Yaroslavl State Univ. (Russian Federation)

The presented paper is of PC modeling of scaled object recognition with the help of invariant correlation filters for optical correlators. The object database consists of objects of true and false classes with different changes of scale. The recognition process consits of two stages-multiclass recognition and geometrical change recognition with the help of filters of different types. The results of modeling present data on comparison of different combination of filter types.

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9478-1, Session 1

Secure communication systems using synchronized Lorenz strange attractor on reconfigurable hardware

Marc M. Sepantaie, The Catholic Univ. of America (United States); Vy Bui, Catholic Univ of America (United States); Esam El-Araby, Amir M. Sepantaie, Georges Nehmatallah, Nader M. Namazi, The Catholic Univ. of America (United States)

The design and implementation of an analog circuit for a synchronized chaotic communication system has been previously investigated. The approach uses the output of a drive system (transmitter) to bring in-line the response system (receiver) so they can securely and harmoniously oscillate in a synchronized fashion [1]. In this paper, we extend the work presented by Cuomo and Oppenheim [1] by utilizing their proposed drive/response system and augmenting it with Haar filtering and appropriate thresholding in order to detect a transmitted random binary message. Using the Lorenz chaotic attractor to obscure the message, we pass it through an Additive White Gaussian (AWG) channel and successfully retrieve the original random binary data. Two distinct communication topographies, Chaotic Masking, and Chaotic Parameter Modulation are simulated using Matlab and implemented using a reconfigurable hardware prototyping tool, namely System Generator for DSP from Xilinx [2].

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9478-3, Session 1

Certificate based key agreement among LTE entities for secure handover

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The increasing popularity of wireless technologies and their application is captivating the attention of users day by day. The latest development in mobile telecommunications is the 4G architecture. LTE (long term evolution) is the candidate of next generation towards 4G in mobile broadband technology which provides a data rate of 100 Mbps and works with IP. It is a newly emerging technology and it offers enhanced speed, coverage and capacity for current mobility networks. As this is with IP based network, ensuring network security during handover is of vital importance. LTE there by presents challenges in the design of security mechanisms due to its distinctive features especially during handover. Hence in this paper, we propose an improved approach such as device certificate based key agreement among the LTE entities. The main objective is to increase the security levels primarily between evolved Node B(eNB) and Mobile Management Entity(MME) and the same status should be followed for MME and Home Subscriber Server(HSS), whenever User Equipment(UE) moves from one eNB to another. The LTE entities should possess certificate provided by Certificate Authority(CA) before communicating with another entity. Thus the communication between the LTE entities is made secure. The proposed technique for fast and secure access by key management is simulated using NS-3.

9478-4, Session 1

Investigating Weaknesses in Android Certificate Security

Daniel E. Krych, Stephen Lange-Maney, Patrick McDaniel, The Pennsylvania State Univ. (United States); William Glodek, U.S. Army Research Lab. (United States)

Android's application market relies on secure certificate generation to establish trust between applications and their users; yet, cryptography is often not a priority for application developers and many fail to take the necessary security precautions. Indeed, there is cause for concern: several recent high-profile studies have observed a pervasive lack of entropy on Web-systems leading to the factorization of private keys [1]. Sufficient entropy, or randomness, is essential to generate secure key pairs and combat predictable key generation. In this paper, we analyze the security of Android certificates. We investigate the entropy present in 550,000 Android application certificates using the Quasilinear GCD Finding Algorithm [1]. Our results show that while the lack of entropy does not appear to be as ubiquitous in the mobile markets as on Web-systems, there is substantial reuse of certificates—only one third of the certificates in our dataset were unique. In other words, we find that organizations frequently reuse certificates for different applications. While such a practice is acceptable under Google's specifications for a single developer, we find that in some cases the same certificates are used for a myriad of developers, potentially compromising Android's intended trust relationships. Further, we observed duplicate certificates being used by both malicious and non-malicious applications. The top 3 repeated certificates present in our dataset accounted for a total of 11,438 separate APKs. Of these applications, 451, or roughly 4%, were identified as malicious by antivirus services.

[1] N. Heninger, Z. Durumeric, E. Wustrow, and J. A. Halderman, “Mining your ps and qs: Detection of widespread weak keys in network devices,” in Proceedings of the 21st USENIX Conference on Security Symposium, ser. Security'12. Berkeley, CA, USA: USENIX Association, 2012, pp. 35–35. [Online]. Available: http://dl.acm.org/citation.cfm?id=2362793.2362828

9478-12, Session 1

The effectiveness of the jammer signal characteristics on Conical-Scan systems

Mehmet C. Sahingil, Murat S. Aslan, TÜB?TAK B?LGEM ?LTAREN (Turkey)

The infrared guided missiles (IRGM) are among the most important threats against air platforms. The IRGM's with seeker which has conical-scan system are one of the most abundant threats. As hard-kill electronic attack (EA) techniques can be used to deceive this type of IRGM's, soft-kill EA techniques can also be used. One of the most effective soft-kill techniques is using jammers.

The conical-scan systems are using modulated signals to find the target location. At the same time, jammers are the systems which emit modulated signals. Because the conical-scan systems are modulating and demodulating the emitted radiation from the target platform, the modulated signals from the jammer will upset the emitted signals from the target platform. Therefore, the jammer systems which emit modulated signals are used to break the tracking lock of the IRGM's seeker.

Nonetheless, to determine the signal characteristics of the jammer is not a trivial issue. To accomplish this, lots of simulations must be run, experiments must be done in hardware in the loop (HIL) laboratories, and even trials must be done where real platforms are used. In this work we present the results of our simulation based investigations. In the simulations, the

typical engagement scenarios between an IRGM with conical-scan seeker and a platform with jammer are run. In the scenarios, the jammer signals are generated and its effectiveness values on seekers were investigated. By using Monte-Carlo batch runs in a pre-determined parameter space, to determine the optimum jammer signal characteristics against specific conical-scan seekers is aimed.

9478-5, Session 2

Adaptive OpenCL libraries for platform portability

Paul A. Fox, Allyssa L. Batten, Stephen Kozacik, Eric J. Kelmelis, EM Photonics, Inc. (United States)

The OpenCL API provides an abstract mechanism for massively parallel programming on a very wide range of hardware, including traditional CPUs, GPUs, accelerator devices, FPGAs, and more; however, these different hardware architectures and platforms function quite differently. Because of these differences, coding OpenCL applications that are usefully portable is challenging. Certain considerations are therefore required in developing an effectively portable OpenCL library in order to enable parallel application development without requiring fully separate code paths for each target platform. By making use of device detection and characterization provided by the OpenCL API, valuable information can be obtained to make runtime decisions for optimization; in particular, the effects of memory affinity change depending on the memory organization of the device architecture. Work partitioning and assignment depend on the device execution model, such as the types of parallel execution supported by the architecture and available synchronization primitives. These considerations, in turn, affect the selection and invocation of kernel code. For certain devices, platform-specific libraries are available, while others can benefit from generated kernel code based on the specified device parameters. By parameterizing an algorithm based on how these considerations affect performance, a combination of device parameters can be used to produce an execution strategy that will provide improved performance for that device or collection of devices.

9478-6, Session 2

Enhanced NVESD EO/IR sensor acquisition life cycle test and evaluation process

Jonathan G. Hixson, Christopher May, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The new testing and evaluation process developed by the NVESD Modeling and Simualtion Division provides end to end systems evaluation and testing of EO/IR sensors. By combining NV-LabCap, NV-IPM, NVIG and OneSAF input sensor file generation, NVESD provides confidence to the M&S community that EO/IR sensor developmental and operational testing and evaluation are accurately represented throughout the lifecycle of an EO/IR system. This new process allows for both theoretical and actual sensor testing. A sensor can be theoretically designed in NV-IPM, modeled in NV-IPM and then seamlessly input into the wargames for operational analysis. After theoretical design, prototype sensors can then be measured by using NV-LabCap then modeled in NV-IPM and input into wargames for further evaluation. The measurement process to high fidelity modeling and simulation can then be repeated again and again throughout the entire life cycle of an EO/IR sensor as needed, to include LRIP, Full rate production, and even after Depot Level Maintenance. This is a prototypical example of how an engineering level model and higher level simulations can share models to mutual benefit. NVESD has demonstrated the experience in this area can benefit other similar modeling efforts.

9478-7, Session 2

An evaluation of algorithms and methods for compressing and decompressing atmospheric transmission data for use in at-sensor measurements

Mark H. Van Benthem, Drew P. Woodbury, Sandia National Labs. (United States)

In this paper, we describe the use of various methods of one-dimensional spectral compression by variable selection as well as principal component analysis (PCA) for compressing multi-dimensional sets of spectral data. We have examined methods of variable selection such as wavelength spacing, spectral derivatives, and spectral integration error. After variable selection, reduced transmission spectra must be decompressed for use. Here we examine various methods of interpolation, e.g., linear, cubic spline and piecewise cubic Hermite interpolating polynomial (PCHIP) to recover the spectra prior to estimating at-sensor radiance. Finally, we compressed multi-dimensional sets of spectral transmittance data from moderate resolution atmospheric transmission (MODTRAN) data using PCA. PCA seeks to find a set of basis spectra (vectors) that model the variance of a data matrix in a linear additive sense. Although MODTRAN data are intricate and are used in nonlinear modeling, their base spectra can be reasonably modeled using PCA yielding excellent results in terms of spectral reconstruction and estimation of at-sensor radiance. The major finding of this work is that PCA can be implemented to compress MODTRAN data with great effect, reducing file size, access time and computational burden while producing high-quality transmission spectra for a given set of input conditions.

9478-8, Session 2

Power aware computing: a directive-based approach

Paul A. Fox, Stephen Kozacik, James Bonnett, Eric J. Kelmelis, EM Photonics, Inc. (United States)

In recent years, powerful and inexpensive mobile processors, originally designed for consumer devices, have opened up opportunities for inexpensive field-deployable systems. A key consideration for systems in the field, however, is endurance. Although increasingly high-performance systems have become available, battery technology has not kept pace. Consequently, the ability to monitor and control power consumption of these embedded systems is highly desirable. With vendor-provided Linux kernel support, a degree of control over power consumption is available; however, the various frameworks affecting power consumption (cpufreq, cpuidle, hotplug, etc.) are not well-integrated and thus not readily usable by application developers. In this paper we detail an approach to unifying these control mechanisms into a single, directive-based interface. In this system, based on a modified Clang compiler, directives can be added to code in similar fashion to OpenMP in order to steer power consumption. These interact with a user-space runtime that then communicates with the various kernel subsystems via the sysfs interface. This system allows code to be easily annotated to steer power consumption in various regions of code without requiring intrusive modification of the underlying code or loss of compatibility with unsupported systems. The runtime can then use the provided policies to optimize performance and power consumption as directed, using both static and dynamic criteria, including performance and power-consumption goals.

9478-9, Session 3

A Reference Model for Model-Based Design of Critical Infrastructure Protection Systems

YoungDon Shin, Samsung Thales Co., Ltd. (Korea, Republic of); Cheol-Young Park, George Mason Univ. (United States); Jae-Chon Lee, Ajou Univ. (Korea, Republic of)

Today's war field environment is getting versatile as the activities of unconventional wars such as terrorist attacks and cyber-attacks have noticeably increased lately. The damage caused by such unconventional wars has also turned out to be serious particularly if targets are major facilities related to banking and finance, transportation, power, information and communication, government, and so on. Such facilities called critical infrastructures are vulnerable to attack and interconnected to each other in many cases. As such, to ensure the security of critical infrastructures is very important and thus the concept of critical infrastructure protection (CIP) has come. The program to realize the CIP at national level becomes the form of statute in each country. On the other hand, it is also needed to protect each individual critical infrastructure. The objective of this paper is to study on an effort to do so, which can be called the CIP system (CIPS). There could be a variety of ways to design CIPS's. Instead of considering the design of each individual CIPS, a reference model approach is taken in the paper. The reference model represents the design of all the CIPS's that have many design elements in common. In addition, a model-based approach is adopted in the development of the reference model. The modeling language used is the systems modeling language (SysML), which is proposed and managed by Object Management Group (OMG) and a de facto standard. Using SysML, the structure and operational concept of the reference model are designed to fulfil the goal of CIPS's, resulting in the block definition and activity diagrams. As a case study, the operational scenario of the nuclear power plant while being attacked by terrorists is studied using the reference model. The effectiveness of the results is also analyzed using multiple analysis models. It is thus expected that the approach taken here has some merits over the traditional design methodology of repeating requirements analysis and system design.

9478-10, Session 3

Modeling and simulation of infrastructure resiliency against man-made hazards

Yahia Al-Smadi, Texas A&M Univ.-Kingsville (United States)

The increasing threat of terrorist attacks on sensitive facilities and structures in the US has sparked great interest to investigate how to design structures, building and military vehicles, to withstand blasts. In order to overcome negative consequences of a disaster, buildings and infrastructures need to be resilient. After a disaster occurs, they must get back to their normal operations as quickly as possible. Buildings and infrastructures should incorporate both pre-event (preparedness and mitigation) and post-event (response and recovery) resilience activities to minimize negative effects of a disaster.

Quantification of resilience can be achieved through the use of loss estimation models. These models have gained considerable attention in recent years, and they have become better established and increasingly practical. New approaches emphasize that loss estimation models could be useful in quantifying resilience. The methodology will be used to different types of buildings to calculate resilience of buildings against man-made hazards by using different types of recovery models. The formulation for the resilience quantification is based on a model embedding several distinct parameters (for example, structural loss ratios, conditional probabilities of exceeding for damage states, estimated and actual recovery times, charge mass probability). A robust three-dimensional computational model will be created using the finite-element software ANSYS combined with a blast analysis using the LS-DYNA software. In addition, a semi-analytical approach will be used, in which the air-blast pressure load simulation from LS-DYNA will be loaded to analytical models of designated structures.

9478-11, Session 3

Focus on connections for successful organizational transformation to model based engineering

Guy Babineau, Northrop Grumman Corp. (United States)

Organizational Transformation to a Model Based Engineering Culture is a significant goal for Northrop Grumman Electronic Systems in order to achieve objectives of increased engineering performance. While organizational change is difficult, a focus on connections is creating success. Connections include model to model, program phase to program phase and organization to organization all through Model Based techniques. This presentation will address the techniques employed by Northrop Grumman to achieve these results as well as address continued focus and efforts. Model to model connections are very effective in automating implicit linkages between models for the purpose of ensuring consistency across a set of models and also for rapidly assessing impact of change. Program phase to phase connections are very important for reducing development time as well as reducing potential errors in moving from one program phase to another. Organization to organization communication is greatly facilitated using model based techniques to eliminate ambiguity and drive consistency and reuse.

9478-13, Session 3

Understanding the impact of blasts from explosions on MEMS

Yahia Al-Smadi, Texas A&M Univ.-Kingsville (United States)

The objective of the proposed works is to advance knowledge and understanding of the mechanical response of Microelectromechanical MEMS devices and their structural components to air blast loading due to explosions. The increasing threat of terrorist attacks on sensitive facilities and structures in the US has sparked great interest to investigate how to design structures, building, soldier helmets and clothes, and military vehicles, to withstand blasts. While microscale sensors are known for their many attractive features, such as low cost, compactness, stability, and accuracy, their use in harsh environment has been limited due to lack of knowledge on their survivability and response and due to concerns about their reliability and survivability in such conditions. This project will present different design guidelines in order to improve the response of MEMS devices against blast. Data on the impact of blast will be acquired through detailed finite-element models, which will then be imported to be used for MEMS simulations. A robust three-dimensional computational model will be created using the finite-element software ANSYS combined with a blast analysis using the LS-DYNA software. In addition, a semi-analytical approach will be used, in which the air-blast pressure load from LS-DYNA will be loaded to analytical models of MEMS devices.

9478-14, Session 3

Target detection and tracking in maritime surveillance mission

Madeleine G. Sabordo, Elias Aboutanios, The Univ. of New South Wales (Australia)

Target detection and tracking is an important element of military operations. Military commanders and personnel have been allocating and continue to allocate resources into the assessment of platforms' performances in target detection, tracking, identification and classification to assist in decision making regarding the allocation of military assets for surveillance missions. We present an application of target detection and tracking by military aircraft in maritime operations. We investigate the performances of Unmanned Aerial Vehicle (UAV) tiers in a joint operation with a helicopter in maritime surveillance mission. Information about the capabilities of the

platforms are taken from the Wikipedia and are therefore 'unclassified'.

The helicopter and UAV are initially embarked on board a military warship. At the commencement of the mission the aircraft will take off, aim toward their altitude and travel at their corresponding optimal speed to the mission first position (waypoint). The helicopter and UAV fly at different altitudes as they perform detection and classification of targets. There is a radar stationed on the warship that tracks the movement of the aircraft. The targets are vessels traversing the region of interest. They vary in size, speed and type of activities. Initial positions and directions of travel of the vessels are randomly generated. It is assumed that the vessels travel at constant speed throughout the duration of the simulation. The aircraft will return to the warship on completion of the mission.

The performances of the aircraft are evaluated based on three metrics: mission time, that is, the time difference between take off and mission completion; percentage of targets detected; and extent of area covered by the aircraft on completion of the mission. The performance of the tracker stationed on the warship is evaluated using the root mean square position errors. Results indicate that the joint operation of the helicopter and the UAV in surveillance mission contributes to better detection of targets and that the tracker is effective in monitoring the motion of the aircraft.

9478-2, Session 4

Dynamic fair node spectrum allocation for ad hoc networks using random matrices

Mark D. Rahmes, George Lemieux, Dave Chester, Harris Corp. (United States); Jerome Sonnenberg, Harris Corp. GCSD (United States)

Dynamic Spectrum Access (DSA) is widely seen as a solution to the problem of limited spectrum, because of its ability to adapt the operating frequency of a radio. 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 the 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, while secondary users opportunistically attempt to radiate at a specific frequency when the primary user is not using it. We populate a spatial radio environment map (REM) database with known information that can be leveraged in an ad hoc network to facilitate fair path use of the DSA-discovered links. Utilization of high-resolution geospatial data layers in RF propagation analysis is directly applicable. Random matrix theory (RMT) is useful in simulating network layer usage in nodes by a Wishart adjacency matrix. We use the Dijkstra algorithm for discovering ad hoc network node connection patterns. We present a method for analysts to dynamically allocate node-node path and link resources using fair division. User allocation of limited resources as a function of time must be dynamic and based on system fairness policies. The context of fair means that first available request for an asset is not envied as long as it is not yet allocated or tasked in order to prevent cycling of the system. This solution may also save money by offering a Pareto efficient repeatable process. We use a water fill queue algorithm to include Shapley value marginal contributions for allocation.

9478-15, Session 4

Virtual sensor tracking using byzantine fault tolerance and predictive outlier model for complex tasks recognition

Vasanth Iyer, Sachin Shetty, Tennessee State Univ. (United States)

In my current research at TSU-TIGER Institute we have used many data-cleaning (FIU-2013 Thesis) algorithms from custom sensors which need pre-processing before a quality value can be read. In a virtual system like Microsoft Kinect which has capability of depth-sensing a 3D model is necessary. So we define a Virtual Sensor which allows to aggregate various thresholds for motion detection, tracking convergence and noise floor compensation. The pre-pre-processing using practical Byzantine algorithms allows to decrease jitters, false positives and miss-classification during real-time tracking. Our model uses a robust data-cleaning to mitigate outliers: by pre-processing for suppressing the outlier; filtering false positives by using predictive analytics of known actions defined by the model (ACCV 2014) to achieve 50% higher accuracy. The virtual sensor model pipe-lining net results can then be shown to aggregate reliable streams : by sensor data-cleaning of spatial data (moving average filtering + Bagging 30%), combining of temporal features over multiple frames (fusion of several sensors reading 10%), and the use of predictive models (Randomforest + Boosting 10%) to compensate outliers.

9478-16, Session 4

Metamaterial based narrowband perfect absorbers

Ahmed S. Sharkawy, Mathew Zablocki, Lumilant, Inc. (United States)

Current bolometers are broadband detectors and tend to absorb broad IR spectrum for thermal imaging. A key issue with these systems is the lack of sensitivity of the sensors in target detection due to blackbody radiation limit. As a result, one of the many important applications such as low concentration chemical detection cannot be performed. A solution to this problem is to employ cryogenic systems where the sensors are cooled either thermoelectrically or with liquid nitrogen which can lead to higher sensitivity in detection. However, one major drawback of these systems is the size, weight and power (SWaP) issue as they tend to be rather bulky and cumbersome which have largely challenged their use in UAV's.

With this in mind, in this effort we aim to develop wavelength selective uncooled sensors that can exceed the sensitivity imposed by the blackbody radiation limit. For this purpose, we will design narrowband absorbers or uncooled focal plane arrays (FPAs) whose sensitivity will be comparable to cryogenic arrays based on Metamaterials (Mtms). More importantly, these newly designed sensors will be able to carry out low concentration biological and chemical detection with reduced SWaP and also perform hyperspectral imaging –critical to many military missions.

9478-17, Session 4

The use of a low-cost visible light 3D scanner to create virtual reality environment models of actors and objects

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

This paper discusses the use of a low-cost 3D scanner that has been developed with a parts cost of approximately USD $5,000 for the creation of actor and object models for use in a virtual reality environment (VRE). The scanner uses visible light sensing to capture both structural as well as texture and color data of a subject. It is comprised of fifty Raspberry Pi single board computers and cameras which are interlinked by Ethernet switches to a central file and control server. This paper discusses the use of this type of scanner to create 3D models for incorporation into a virtual reality environment. It describes the basic scanning process (which takes under a minute – inclusive of system power up time – for a single scan), which can be repeated to collect multiple positions, if needed for actor model creation.

Following a brief discussion of the requisite quality for VRE incorporation and consideration of whether the low-cost visible light scanner can provide sufficient quality, the paper considers the utility of this approach. First, the efficacy of visible light versus other scanner types is discussed. Particular benefits, such as the ability to capture color and texture data, and drawbacks (such as potentially reduced accuracy, as compared to laser or

blue light projection scanners) are considered. Next, the benefits of wider access to the technology (due to the low cost level) are discussed. Potential for small business and educational use, as well as use in other environments are considered. Finally, the paper discusses prospective next steps to make the technology more widely available, before concluding.

9478-18, Session 4

Physical environment virtualization test bed for human activities recognition

Azin Poshtkar, Vinayak Elangovan, Amir Shirkhodaie, Tennessee State Univ. (United States); Alex L. Chan, Shuowen Hu, U.S. Army Research Lab. (United States)

Human activity recognition research relies heavily on appropriate datasets to verify and validate performance of activity recognition algorithms. Obtaining real datasets, however, are expensive and highly time consuming. A physics-based multi-sensor virtual simulation can accelerate the development of human activity recognition algorithms and techniques by generating relevant training and testing scenarios under various operational conditions. In this paper, we present and demonstrate a newly developed virtual simulation modeling (VSM) architecture, called IRIS, to generate calibrated multi-source imagery datasets suitable for development and testing of recognition algorithms for context-based human group activities taking place in the virtual world space. This architecture serves as a versatile testbed to generate a vast amount of photo-realistic data for the training and testing of sensor processing algorithms. This paper presents the framework of VSM, including the emplacement of various imagery sensors within a simulated environment, and describes its effectiveness and efficiency in generating high fidelity imagery data for in-vehicle human activity recognition under different operational contexts and from a broad range of camera viewing perspectives, as well as operating under various simulated environmental conditions. Finally, we demonstrate several image processing techniques for the recognition of in-vehicle human activity using the datasets generated by the VSM architecture.

9478-19, Session PSTue

Building GSM network in Extreme Conditions

Martin Mikulec, Miroslav Voznak, Marcel Fajkus, Pavol Partila, Jaromir Tovarek, Zdenka Chmelikova, V?B-Technical Univ. of Ostrava (Czech Republic)

The paper deals with presentation of own mobile network solution based on open source software and low-cost hardware. The created Base Transmission Station (BTS) can be deployed and put into operation in a few minutes in a required area to ensure private communication between connected GSM mobile terminals. The BTS station works on a standard GSM frequency bands, so the traditional cell phones can be used as the mobile terminals.

Convergence between BTS station and other networks is possible through IP network. Paper tries to define connection parameters to provide sufficient quality of voice service between connected networks. The most influence connection parameters are availability, latency, packet loss, jitter and delay.

Paper brings practical results of voice calls simulations between users inside BTS station network and users inside IP Multimedia Subsystem (IMS) system network.

Paper, apart from the quality measurement section, describes technical requirements for successful interconnection between BTS and IMS networks. End users need to be authenticated, authorized and accounted for the provided services.

The communication between BTS station and connected networks has to be secured against interception of the third party. There are many solutions, how to secure the communication channel. Paper tries to compare these securing methods according to their influence to the quality of the voice service.

The calls are simulated by low-cost embedded solution for speech quality measurement in GSM network. This tool is under development of our laboratory and allows automatic speech quality measurement of any GSM or UMTS mobile network. The Perceptual Evaluation of Speech Quality (PESQ) method is used to get final comparable results.

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9479-1, Session 1

Reconfigurable technologies and architectures for phased array antennas: an overview of the DARPA ACT program

(Invited Paper)

Roy H. Olsson III, Defense Advanced Research Projects Agency (United States)

No Abstract Available

9479-2, Session 1

Methodologies to analyze and explore the impact of technological and operational changes on the fully burdened cost structure of the global force structure

(Invited Paper)

Mitchell W. Kossar, Benjamin Rogers, First Principles Advisory Group (United States)

Given today's austere economic environment and the rapid pace of technological change, it is more important than ever to be able to cost out affordable systems and at the same time determine the impact the system has on the entire force structure in which it operates. First Principles Advisory Group has developed a methodology to analyze and explore the impact of technological and operational changes on the fully burdened cost structure of the global force structure. Our analysis is rooted in first principles on the physical parameters of the operating concepts and how technology unleashes or creates new concepts within those physical bounds. In this paper, we discuss our methodology and provide examples of how our analysis provides clarity and insight into high level technology decisions.

9479-3, Session 1

GTRI software defined modular array antenna

Richard T. Lee, Ryan S. Westafer, Georgia Tech Research Institute (United States)

No Abstract Available

9479-4, Session 1

Optically controlled GeTe phase change switch and its applications in reconfigurable antenna arrays

Loc Chau, James Ho, Xing Lan, Northrop Grumman Aerospace Systems (United States); Robert M. Young, Doyle Nichols, Nabil El-Hinnawy, Northrop Grumman Electronic Systems (United States); Nima Ghalichechian, John Volakis, The Ohio State Univ. (United States)

No Abstract Available

9479-5, Session 1

Impact: a low cost reconfigurable digital beamforming common module building block for next generation phased arrays

Lee Paulsen, Ted Hoffmann, Charlie Nguyen, Rockwell Collins, Inc. (United States)

No Abstract Available

9479-6, Session 1

Higher-order N-path filters and active cancellation techniques for interference mitigation and STAR in digital array receivers

Harish Krishnaswamy, Jin Zhou, Negar Reiskarimian, Columbia Univ. (United States)

No Abstract Available

9479-7, Session 1

Vanadium dioxide phase change switches

Mark Field, Christopher Hillman, Philip Stupar, Jonathan Hacker, Zachary Griffith, Teledyne Scientific Co. (United States); Kang-Jin Lee, Teledyne Scientific & Imaging, LLC (United States)

We have built RF switches using vanadium dioxide thin films fabricated within a section of inverted transmission line with integrated on chip heaters to provide local thermal control. On heating the films above the metal insulator transition we obtain record low switch insertion loss of -0.13 dB at 50 GHz and -0.5 dB at 110 GHz. We investigate the device physics of these switches including the effect of a deposited insulator on the VO2 switching characteristics, the self-latching of the devices under high RF powers and the effect of resistance change with temperature on the device linearity. Finally we show how these devices can be integrated with silicon germanium RF circuits to produce a field programmable device where the RF signal routing can be selected under external control.

9479-8, Session 2

DOD product lines: a holistic strategy for defense open business models *(Invited Paper)*

Robert Matthews, Naval Air Systems Command (United States)

No Abstract Available

9479-9, Session 2

A systems approach to achieving the benefits of open and modular systems

Gavin Pearson, Defence Science and Technology Lab. (United Kingdom); Richard Smith, IBM United Kingdom Ltd. (United Kingdom); Howard Tripp, Chemring EOD Ltd. (United Kingdom)

The ability to evolve Communication and Information Systems (CIS) effectively and affordably is enhanced by the adoption of open and modular system architectures. However, there are a number of issues with actually achieving these benefits in practice.

This paper presents the results of an initial system study into blockers to the achievement of the benefits of open and modular systems. In particular, the study and this paper, focuses on the issues associated with:

• the rapidly evolving Information & Communications Technology landscape;

• the commercial approach to the procurement of CIS systems;

• the evolution of such systems in safe and secure manner.

9479-10, Session 2

Q-learning and p-persistent CSMA based MAC protocol for cognitive radio networks operating with shared spectrum activity

Clifton L. Watson, Air Force Research Lab. (United States); Subir Biswas, Michigan State Univ. (United States)

Cognitive radio (CR) technology can provide the additional spectrum required to support the growing need for spectral bandwidth. Based on software-defined technology, CRs are capable of sensing the spectrum environment and identifying opportunities for spectrum access. Under a policy known as dynamic spectrum access (DSA), CRs operate as unlicensed secondary users that can temporarily access the idle portions of licensed spectrum on the condition that minimal to no interference is caused to licensed primary users (PUs). In a multi-channel DSA environment, the goal of CR networks is to attain the highest possible throughput achievable while preventing or minimizing PU interference (PUI). This is a very challenging problem due to the unpredictable behavior of PUs. This problem is further exacerbated by collisions among nodes. Thus, to achieve this goal, CR networks must rely on a medium access control (MAC) protocol to dynamically allocate the set of available channels and coordinate the channel access of CR nodes, such that: (1) network throughput is maximized, (2) PUI is minimized, and (3) collisions are minimized. We propose a MAC protocol based on Q-learning and the p-persistent channel access scheme. The proposed protocol utilizes Q-learning to learn which channels are more favorable for a higher network throughput and thus allocates those channels accordingly. The protocol also adapts the transmission probability p of CR nodes to minimize collisions and PUI. We demonstrate through simulation that the proposed protocol provides greater spectrum efficiency and utilization than existing protocols for DSA environments with varying dynamics of PU activity.

9479-11, Session 2

Open architecture design and approach for the integrated sensor architecture (ISA)

Christine L. Moulton, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Jared J. Hepp, John Harrell, Oakwood Controls (United States); Michael Kogut, SAIC (United States); Alan T. Krzywicki, U.S. Army NVESD (United States)

In the Army there is a pressing need to effectively enhance the Soldiers' situational awareness by accessing modern sensing capabilities. This need leads to numerous integration efforts to tie a selection of sensors together to create a coherent picture of the battlefield. Sadly, these efforts often rely on stove-piped solutions where the software pieces are designed to communicate using the specific protocols of the selected systems. This approach does not allow for much flexibility in deployment and future enhancement requires significant investment. Often, any plug-and-play capability comes not from design but from luck that one of sensors uses a more common protocol.

Integrated Sensor Architecture (ISA) is designed in response to these stove-piped systems. The design, based on the principals of Service Oriented Architectures (SOA) and Open Architectures, addresses the problem of integration itself, and is not designed for specific sensors or systems. The use of SOA and Open Architecture approaches has led to a flexible, extendable architecture.

Using these approaches, and supported with common data formats, open protocol specifications, and DODAAF system architecture documents, an integration focused architecture has been developed. ISA can help move the Army from stove-pipe and costly solutions to a more cost-effective, plug-and-play design.

9479-12, Session 2

Architecting open AUV systems

Dani Goldberg, Bluefin Robotics Corp. (United States)

As Autonomous Underwater Vehicle (AUV) systems increase in sophistication, there is a corresponding increase in the number and complexity of integrated subsystems. Modern AUV systems contain hardware and software components from a myriad of different manufacturers and sources, organized and integrated into major subsystems that provide a useful level of functionality to users (or operators) of these systems. At the top-level, an AUV system architecture may be described in terms of three major subsystems: vehicle, advanced autonomy, and payload. In order to ease integration of these subsystems, it is highly desirable to have open interfaces between them that are well-described, well-behaved and standardized, if possible. Lacking such open interfaces not only leads to added cost and complexity in integration, but also results in an AUV system that is more difficult to maintain and less flexible for end users. The fact that each subsystem (vehicle, advanced autonomy, payload) often includes a degree of autonomy places even greater onus on the architecture and interfaces in creating a well-behaved system.

In this paper, we provide a top-level view of the autonomy architecture of an AUV, both within and between the three major subsystems -- vehicle, advanced autonomy, and payload. For each element, we highlight the need for architecture/interface openness and indicate the current state of practice. Finally, by way of example, we describe how Bluefin Robotics Corporation is architecting open AUV systems.

9479-13, Session 2

Modular open RF architecture: extending VICTORY to RF systems

Jason Dirner, Vistronix (United States)

Radio frequency products spanning multiple functions have become increasingly critical to the warfighter. Military use of the electromagnetic spectrum now includes communications, electronic warfare (EW), intelligence, and mission command systems. Due to the urgent needs of counterinsurgency operations, various quick reaction capabilities (QRCs) have been fielded to enhance warfighter capability. Although these QRCs were highly successfully in their respective missions, they were designed independently resulting in significant challenges when integrated on a common platform.

This paper discusses how the Modular Open RF Architecture (MORA) addresses these challenges by defining an open architecture for multifunction missions that decomposes monolithic radio systems into high-level components with well-defined functions and interfaces. The functional decomposition maximizes hardware sharing while minimizing added complexity and cost due to modularization. MORA achieves significant size, weight and power (SWaP) savings by allowing hardware such as power amplifiers and antennas to be shared across systems. By separating signal conditioning from the processing that implements the actual radio application, MORA exposes previously inaccessible architecture points, providing system integrators with the flexibility to insert third-party capabilities to address technical challenges and emerging requirements.

MORA leverages the Vehicular Integration for Command, Control, Communication, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR)/EW Interoperability (VICTORY) framework. This paper concludes by discussing how MORA, VICTORY and other standards such as OpenVPX are being leveraged by the U.S. Army Research, Development, and Engineering Command (RDECOM) Communications Electronics Research, Development, and Engineering Center (CERDEC) to define a converged architecture enabling rapid technology insertion, interoperability and reduced SWaP.

9479-14, Session 4

DARPA perspective on open architectures *(Invited Paper)*

John Shaw, Defense Advanced Research Projects Agency (United States)

No Abstract Available

9479-15, Session 4

Open mission system overview *(Invited Paper)*

Eric Koper, U.S. Air Force (United States)

No Abstract Available

9479-16, Session 4

Overview of DARPA CODE program *(Invited Paper)*

Jean-Charles Lede, Defense Advanced Research Projects Agency (United States)

No Abstract Available

9479-17, Session 4

Open architecture flexible weapons *(Invited Paper)*

Jonathan Shaver, Air Force Research Lab. (United States)

No Abstract Available

9479-18, Session 5

Executable architecture management system *(Invited Paper)*

Jeff Monroe, Metron, Inc. (United States)

No Abstract Available

9479-19, Session 8

Challenges in RF convergence *(Invited Paper)*

Vincent Sabio, Defense Advanced Research Projects Agency (United States)

No Abstract Available

9479-20, Session 8

Development of a video SAR for FMV through clouds *(Invited Paper)*

H. Bruce Wallace, Defense Advanced Research Projects Agency (United States)

No Abstract Available

9479-22, Session 8

A common open systems architecture for ISR sensor payloads *(Invited Paper)*

Gibbs Dickson, U.S. Air Force (United States)

No Abstract Available

Conference 9480: Fiber Optic Sensors and Applications XII

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9480-1, Session 1

Fiber optic sensors for structural monitoring: a 30 year perspective *(Invited Paper)*

Eric Udd, Columbia Gorge Research LLC (United States)

This paper reviews fiber optic smart structure developments associated with the authors experience at McDonnell Douglas, Blue Road Research and Columbia Gorge Research over a 30 year period. The work described involves participation by those organizations as well as cooperating organizations and sponsors.

9480-2, Session 1

Fiber optic sensing goes mainstream *(Invited Paper)*

Tom W. Graver, Micron Optics, Inc. (United States)

Since the mid-nineties, fiber optic sensing applications have sprouted in niches from aerospace vehicles to oil wells and marine vessels to medical devices. But the broader adoption of FOS has been slow. That's changing now. More polished interrogators, comprehensive software, and packaged sensors are being combined and deployed as specific solutions rather than general tools. This presentation will unveil what technologies have changed to make this possible and will provide a view into applications that are turning from niche to mainstream.

9480-3, Session 1

Insight into fiber Bragg sensor response at 100-MHz interrogation rates under various dynamic loading conditions *(Invited Paper)*

George Rodriguez, Marcelo Jaime, Laura Smilowitz, Bryan F Henson, Chuck H Mielke, Fedor F Balakirev, Ross D McDonald, Richard L Sandberg, Abul Azad, Los Alamos National Lab. (United States); Bruce R Marshall, Brandon M La Lone, National Security Technologies, LLC (United States)

A coherent pulse time domain approach is used to interrogate fiber Bragg grating response to stress at a 100 MHz rate. The approach is quite useful for ultra high speed dynamic events where nanosecond level response to dynamic stress loading conditions are desired. In this presentation, I highlight the approach and its advantages over traditional incoherent interrogation systems. The presentation will include examples using this new approach where fast system response is required: pressure sensing of thermal ignition and burn in high explosives, high pressure shock wave sensing, and material strain sensing in ultra-high pulsed magnetic fields. All of these examples require sensing with a time resolution below one microsecond, and the system is proving to be useful for development of fiber Bragg grating based sensing in extreme environments.

9480-44, Session 1

In-situ monitoring of drug release from therapeutic eluting polyelectrolyte multilayers under static and dynamic conditions

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); Paula T. Hammond, Massachusetts Institute of Technology (United States); Henry H. Du, Stevens Institute of Technology (United States)

The release profiles of gentamicin sulfate (GS) from [chitosan (CHI)/poly(acrylic acid) (PAA)/GS/PAA]n polyelectrolyte multilayers were investigated in situ using an innovate lab-on-fiber (LOF) optofluidic platform that mimics physiologically relevant fluid flow in a microenvironment. The LOF was constructed by enclosing in a flow-enabled and optically coupled glass capillary a long-period fiber grating both as a substrate for LbL growth of [CHI/PAA/GS/PAA]n and a measurement probe for GS release. We show that the LOF is very robust in monitoring the construction of the [CHI/PAA/GS/PAA]n multilayers at monolayer resolution as well as evaluating the rate of GS release with high sensitivity and high speed. The release processes in the LOF under static and a range of dynamic conditions are evaluated, showing a faster release under dynamic condition than that under static condition due to the varying circumstance of GS concentration gradient and the effect of flow-induced shear at the medium-multilayer interface. The LOF platform has the potential to be a powerful test bed to facilitate the design and evaluation of drug-eluting polyelectrolyte thin films for their clinical insertion as part of patient care strategy.

9480-4, Session 2

Distributed Rayleigh scatter dynamic strain sensing above the scan rate with optical frequency domain reflectometry

Stephen T. Kreger, Justin Klein, Nur Aida Abdul Rahim, Joseph J. Bos, Luna Innovations Inc. (United States)

Luna recently demonstrated a novel optical phase-based algorithm for removing the adverse effects of fiber motion at frequencies far above the scan rate on high-resolution measurements of Rayleigh scatter using Optical Frequency Domain Reflectometry (OFDR) for static strain and temperature measurements. By comparing dynamic OFDR Rayleigh scatter measurements to a static reference, it is possible to extract the time-varying phase signal in real time. The same algorithm, applied to successive segments along an unbonded single mode fiber, is an effective means of monitoring the spatial distribution of high frequency optical phase perturbations caused by vibration and acoustic wave propagation in the fiber. We will discuss tradeoffs between scan speed, scan duration, range, spatial resolution, vibration sensitivity and vibration frequency range, provide measurement examples, predict limiting specifications for practical system performance based on current commercial OFDR products, and compare these limits to those of distributed acoustic sensing techniques based on Optical Time Doman Reflectometry.

9480-5, Session 2

Interrogating adhesion using fiber Bragg grating sensing technology

Roger D. Rasberry, Garth D. Rohr, William K. Miller, Sandia National Labs. (United States); Eric Udd, Columbia Gorge Research LLC (United States); Noah T. Blach, U.S. Air Force Academy (United States); Ryan A. Davis, Sandia National Labs. (United States); Walter R. Olson, Sandia National Labs (United States); David Calkins, R. Allen Roach, David S. Walsh, James R. McElhanon, Sandia National Labs. (United States)

The assurance of the integrity of adhesive bonding at substrate interfaces is paramount to the longevity and sustainability of encapsulated components. Unfortunately, it is often difficult to non-destructively evaluate these materials to determine the adequacy of bonding after manufacturing and then later in service. A particularly difficult problem in this regard is the reliable detection/monitoring of regions of weak bonding that may result from poor adhesion or poor cohesive strength, or degradation in service. One promising and perhaps less explored avenue we have recently begun to investigate for this purpose centers on the use of fiber Bragg grating sensing technology. In this scenario, a grating is patterned into a fiber optic such that a broadband spectral reflectance is observed. The sensor is highly sensitive to local and uniform changes across the length of the grating. Our initial efforts to evaluate this approach for measuring adhesive bonding defects at substrate interfaces will be presented.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

9480-6, Session 2

Residual internal stress optimization for EPON 828/DEA thermoset resin using fiber Bragg grating sensors

Garth D. Rohr, Amy L. Kaczmarowski, Mark Stavig, Cory Gibson, Sandia National Labs. (United States); Eric Udd, Columbia Gorge Research LLC (United States); R. Allen Roach, Roger D. Rasberry, Sandia National Labs. (United States); Brendan Nation, Sandia National Labs (United States)

Internal residual stress and overall mechanical properties of thermoset resins are largely dictated by the curing process. It is well understood that fiber Bragg grating (FBG) sensors can be used to evaluate temperature and cure induced strain while embedded during curing. Herein, is an extension of this work whereby FBGs are used to identify a curing process that leads to minimized stress in an unfilled and filled Epon 828/DEA resin. Variables affecting stress including cure cycle, mold (release), and adhesion promoting additives will be discussed and stress measurements from a strain gauge pop-off test will be used as comparison.

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9480-7, Session 3

Influence of dynamic thermal effects on durability of optical fiber in the fiber optic temperature sensor

Alexandre V. Polyakov, Belarusian State Univ. (Belarus)

Fiber-optic sensors (FOSs) have ability to work at influence of intensive electric and magnetic fields, firmness to excited environments, explosion safety, not less important advantage is possibility of creation of the distributed (multi-point) measuring systems on their basis. It means that the same fiber-optic sensor can be used for performance of measurements in a considerable quantity of space points. Thus the obtained data is transferred in the form of spatial distribution of the corresponding measured value.

The new structure of the multi-point fiber-optic temperature sensor intended for in-situ thermometry at extraction of high-viscosity oil is presented. We consider that high sensitivity of recirculation frequency in closed optoelectronic system to small external influences on fiber optic path will allow to realize a new principle of frequency representation of the information. The principle of measurements is based that temperature influence leads to change of length and refraction index of a fiber. The action principle is based on registration recirculating frequency of single pulses with their periodic regeneration on various wavelengths. Sensitive elements are sections of an optical fiber with the metal covering, divided spectral-selective reflecting elements.

At high temperatures in the optical fiber mechanical stress will occur because the thermal expansion coefficient of the metallic coating is significantly greater then coefficient of the optical fiber. Under conditions of high temperature, dynamically changing and acting years, there will occur a gradual destruction. This phenomenon, called static fatigue of glass, is explained by the growth of existing defects in glass, and it leads to the decrease of durability of the fiber. In this regard, there is the problem assessing the impact of time-varying high temperature on the strength of the optical fiber.

The method of a theoretical estimation of optical fiber durability used in optical fiber sensors as a sensitive element, depending on the strain arising at dynamic changes of temperature, pressure and other mechanical influences is offered. The developed analytical model takes into account design features of a fiber (diameters of a core and cladding, a metal or polymeric covering), doping types, relative humidity of an environment. Numerical modeling of optical fiber's lifetime at dynamic influences of measured temperature and comparison with experimental data is carried out.

9480-8, Session 3

Fiber optic anemometer based on silicon Fabry-Perot interferometer

Ming Han, Guigen Liu, Univ. of Nebraska-Lincoln (United States); Weilin W. Hou, U.S. Naval Research Lab. (United States)

Anemometers have been finding vast applications in all kinds of industrial processes, such as process control, food quality surveillance, wind turbines, environment monitoring, etc. In this paper, we propose a new anemometer which consists of a tiny silicon Fabry-Perot interferometer (FPI) mounted on the end of an optical fiber. The anemometer takes advantage of the superior thermal and optical properties of silicon. Silicon is transparent within infrared wavelength range, while it absorbs visible light. Thus, the silicon FPI can be heated by a beam injected from a red diode laser while the infrared signals go through it without any influence. The heat flux flowing out of the silicon film will increase when the sensor is placed in wind, which induces decrease in the optical path of the silicon FPI and thus blue shifts the output spectrum. Such a anemometer is theoretically analyzed and experimentally demonstrated. A higher wind speed corresponds to a larger wavelength shift. By tuning the heating power, the response range of the anemometer is changed. The proposed sensor features simple structure and low cost.

9480-9, Session 3

High-resolution wavelength shift detection of optical signals with low-cost compact readouts

Peter Kiesel, Alex Hegyi, Ajay Raghavan, Alexander Lochbaum, Julian Schwartz, Bhaskar Saha, Anurag Ganguli, Kyle Arakaki, PARC, a Xerox Co. (United States)

Fiber-optics (FO) have shown great potential for distributed sensing in various harsh environment applications. They have a number of advantages in terms of high-resolution capabilities, inherent EMI immunity, low weight/volume of FO, and multiplexing capabilities. However, their widespread adoption in commercial applications has been considerably limited by the high cost, size, weight, and lack of capabilities of the readout unit used to interpret the FO signals. PARC has developed a breakthrough wavelength shift detection (WSD) technology that is capable of reading out signals from wavelength-encoded FO and other optical sensors with high sensitivity using a compact, low-cost unit. An initial prototype demonstrated the ability of this technology to resolve optical wavelength shifts as small as 5 fm at 10 Hz in the C-band, which is substantially better than the state-of-the-art. Recently, the PARC WSD capabilities have been extended with respect to three different performance metrics: a) multiplexed WSD of multiple sensors (10s-100s); b) high bandwidth WSD (1 MHz); and c) WSD in broadband visible spectra (1 pm shifts over 100 nm bandwidth). All these have been achieved while retaining the cost (few 100 dollars when mass-manufactured) and size advantages and comparable resolution of the WSD technology. These interesting developments will be described in the context of an ongoing project where we are exploring fiber-optic sensing for next-gen battery management systems.

9480-10, Session 4

Applications for fiber optic sensing in the upstream oil and gas industry

Christopher S. Baldwin, Weatherford International Ltd. (United States)

Fiber optic sensing has been used in an increasing number of applications in the upstream oil and gas industry over the past 20 years. In some cases, fiber optic sensing is providing measurements where traditional measurement technologies could not. This paper will provide a general overview of these applications and describe how the use of fiber optic sensing is enabling these applications. Technologies such as Bragg gratings, distributed temperature and acoustic sensing, interferometric sensing, and Brillouin scattering will be discussed.

Applications for optic sensing include a range of possibilities from a single pressure measurement point in the wellbore to multizone pressure and flow monitoring. Some applications make use of fully distributed measurements including thermal profiling of the well. Outside of the wellbore, fiber optic sensors are used in applications for flowline and pipeline monitoring along with riser integrity monitoring.

Applications to be described in this paper include in-flow profiling, well integrity, production monitoring, and steam chamber growth. These applications will cover well types such as injectors, producers, hydraulic fracturing, and thermal recovery. Many of these applications use the measurements provided by fiber optic sensing to improve enhanced oil recovery operations. The growing use of fiber optic sensors is providing improved measurement capabilities leading to the generation of actionable data for enhanced production optimization. This not only increases the recovered amount of production fluids but can also enhance wellbore integrity and safety.

9480-11, Session 4

Operational verification of a blow out preventer (BOP) utilizing fiber Bragg grating based strain gauges

Alan Turner, Dan Thibodeau, Philippe Loustau, Lloyd's Register Energy-Drilling (United States)

Ultra-deep water BOP operation poses numerous challenges in obtaining accurate knowledge of current system integrity and component condition- a salient example is the difficulty of verifying closure of the pipe and shearing rams during and after "kick" events. Ascertaining the integrity of these functions is currently based on a manual gallon count performed with a stop watch. Advances in sensor technology now permit more accurate methods of BOP condition monitoring. Fiber optic sensing technology and particularly fiber optic strain gauges have evolved to a point where we can derive a good representation of what is happening inside a BOP by installing sensors on the outside shell. Function signatures can be baselined to establish thresholds that indicate successful function activation. Based on this knowledge base, signal variation over time can then be utilized to assess degradation of these functions and subsequent failure to function. Monitoring the BOP from the outside has the advantage of gathering data through a system that is independent of the OEM, which could then be interfaced with risk based integrity management software and/or a smart monitoring system that analyzes BOP control redundancies. The paper will present the results of ongoing work on a fully instrumented 3'1/2" pipe ram. Instrumentation includes electrical based pressure transducers, accelerometers, flow meters, and optical strain gauges. Correlation will be presented between flow, pressure, acceleration signatures and the fiber optic strain gauge's response as it relates to functional verification and component level degradation trending.

9480-12, Session 4

Optical fiber sensor based on Mach-Zehnder interferometer for monitoring CO_2 in carbon sequestration application

Luis B. Melo, Geoff Burton, Peter Wild, Univ. of Victoria (Canada)

The utilization of a fiber optic sensor to monitor dissolution of carbon dioxide (CO2) in aqueous solutions at geological sequestration pressures is presented. Carbon capture and sequestration (CCS) has been identified as an attractive solution for large-scale reduction of CO2 emissions. CCS consists of capturing CO2 from major emission facilities, such as coal power plants, and subsequent injection for long term storage in underground storage reservoirs.

Saline aquifers are currently the most attractive option for CCS due the high number of available sites, relative proximity to the major CO2 emission sources and large storage potential. Liquid CO2 injected into a saline aquifer is expected to migrate as a plume and slowly dissolve in the formation water. Concerns associated with geological storage of CO2 include sealing properties of the caprock layer located above saline aquifers, potential leakage from the storage site into shallow aquifers and consequent degradation of ground water quality, and potential leakage into the land surface leading to the increased atmospheric CO2 concentrations. Therefore, development of reliable technology for monitoring, verification and accounting (MVA) geological CO2 storage is a critical aspect of carbon sequestration.

This article presents the investigation of a fiber optic sensor based on a Mach-Zehnder interferometer configuration for monitoring dissolution of liquid CO2 in water at 1400 psi. The Mach-Zehnder interferometer is developed by splicing a segment of 35 mm of a photonic crystal fiber between standard single mode fibers. The mechanism of detection of CO2 is based on the sensitivity of the sensor to the surrounding refractive index. The wavelength shift of the interference pattern of the Mach-Zehnder interferometer is monitored as liquid CO2 is injected in a custom-built high pressure vessel.

9480-13, Session 4

Adapting long gauge vibrofibre to measure fracking activities down well for successful oil and gas exploration and production

Peter Kung, QPS Photronics Inc. (Canada); Maria I. Comanici, McGill Univ. (Canada)

The long Gauge Vibrofibre, a newly developed distributed vibration sensor which involves terminating a long length of ordinary Telecom fiber of up to one kilometer with an in-fiber cavity structure, shows the entire structure can detect vibrations over a wide frequency range of 5 Hz to 2,000 Hz. The sensing fiber muse be packaged loosely in a 900 micron Teflon tube to protect the sensor. QPS has performed further experiment and adapt the sensing fiber to be a germanium free, pure core fiber and the terminating cavity on the same fiber type. The cavity is written with Femto second laser creating damaged gratings which works well up to 500 degrees C. If both sensing fiber and cavity involves polyimide fiber, the solution would be ready for down well application, where there is high temperature and pressure. Additional refinement was performed on the laser transmitter: first we optically locked the laser to reduce its line width and achieve longer coherent length. The sensing fiber can therefore be extended to several kilometers. The performance of this new solution will not be affected by photo darkening due to hydrogen ingress; there is no germanium doping usually found in standard Telecom fiber for hydrogen to react, causing optical loss. The power of the laser can also be optimized to reduce detector saturation resulting in improved signal to noise. This new technology relies on analysis of the vibration spectrum to indicate production activities. The terminating cavity can be used to monitor the worst case temperature down the well. A simpler and lower cost version of the solution can be introduce to monitor the vibration of the wind turbine Generator, the gear box and the blade, the fiber simply becomes routed through all the critical components and record vibration signature giving diagnostic information.

9480-14, Session 4

Sub-Hz C-band diode laser for oil exploration

Wei Liang, Vladimir S. Ilchenko, Elijah B. Dale, Danny Eliyahu, Anatoliy A. Savchenkov, Andrey B. Matsko, David J. Seidel, Lute Maleki, OEwaves, Inc. (United States)

Fiber-optic sensors are widely used for remote and in-situ exploration in the oil and gas industry. These include distributed temperature profile monitoring, distributed dynamic strain measurements, and probing of multi-phase flows. Sensing is usually performed at low, nearly acoustic, spectral frequencies, where the achievable signal to noise ratio and sensitivity affected by frequency fluctuations of the optical source. Historically, fiber lasers have been used as the optimal coherent light sources because of their excellent low noise at small Fourier frequencies. Conventional semiconductor lasers, by contrast, have significantly larger frequency noise, and cannot serve the needs of advanced optical sensors. Given their relatively low cost, and their immunity to environmental perturbations such as temperature and vibration, semiconductor lasers with noise at the level of fiber lasers are highly desired for optical sensor applications. In this presentation, we show a heterogeneously-integrated semiconductor laser system based on coupling with a whispering gallery mode resonator. The large quality factors of WGM resonators can be utilized to reduce the linewidth of the semiconductor laser by a factor of a million. A laser based on this scheme is shown to outperform existing fiber lasers, with a demonstrated instantaneous linewidth of 500 mHz and an integrated linewidth of 100 Hz. The laser exhibits frequency drift of less than 10 MHz over many days. Furthermore, the frequency of the laser can be modulated at a GHz span with 100 kHz rate using the laser's integrated tuning element. This is a significantly higher performance than achievable modulation with fiber lasers.

9480-42, Session 4

Novel sensing materials for harsh environment subsurface pH sensing applications *(Invited Paper)*

Congjun Wang, Xin Su, Thomas Brown, Paul R. Ohodnicki Jr., National Energy Technology Lab. (United States)

Unconventional, deep, and ultradeep oil and natural gas resources have become an increasingly important part of the domestic US energy supply requiring harsh environment compatible sensors that can provide real-time information about parameters relevant for monitoring of drilling and fracking processes, well-bore integrity, and environmental monitoring. Parameters of interest include temperature, pressure, flow, and chemistry with the latter being particularly challenging under high pressure and high temperature conditions. This presentation will outline a recently established effort at the National Energy Technology Laboratory targeted at research and development of functional sensor material enabled optical fiber sensors for aggressive subsurface sensing applications.

9480-15, Session 5

Specialty fiber optic applications for harsh and high radiation environments *(Invited Paper)*

Brian G Risch, Prysmian Group (United States)

Since the first commercial introduction in the 1980s, optical fiber technology has undergone an almost exponential growth. Currently over 2 billion fiber kilometers are deployed globally with 2014 global optical fiber production projected to exceed 300 million fiber kilometers. Along with the staggering growth in optical fiber production and deployment, an increase in optical fiber technologies and applications has also followed. Although the main use of optical fibers by far has been for traditional data transmission and communications numerous new applications are introduced each year.

Initially the practical application of optical fibers was limited by cost and sensitivity of the optical fibers to stress, radiation, and other environmental factors. Tremendous advances have taken place in optical fiber design and materials allowing optical fibers to be deployed in increasingly harsh environments with exposure to increased mechanical and environmental stresses while maintaining high reliability. With the increased reliability, lower cost, and greatly expanded range of optical fiber types now available, new optical fiber deployments in harsh and high radiation environments is seeing a tremendous increase for data, communications, and sensing applications.

An overview of key optical fiber applications in data, communications, and sensing for harsh environments in industrial, energy exploration, energy generation, energy transmission, and high radiation applications will be presented. Specific recent advances in new radiation resistant optical fiber types, other specialty optical fibers, optical fiber coatings, and optical fiber cable materials will be discussed to illustrate long term reliability for deployment of optical fibers in harsh and high radiation environments.

1 Patrick J. Fay, CRU International, "Market Update on Global Optical Cable Demand", 63rd International Wire and Cable Symposium, 2014, Providence, RI.

9480-16, Session 5

A polarization maintaining fiber optimized for high temperature gyroscopes

Frank Tutu, Fibercore Ltd. (United Kingdom); Mark D Hill, Fibercore Limited (United Kingdom); Judith Hankey, Andy M. Gillooly, Fibercore Ltd. (United Kingdom)

Fiber optic gyroscopes (FOGs) are being used within increasingly severe environments, requiring operational temperatures in excess of the standard operating range for FOGs. Applications requiring these higher temperatures include: directional drilling of wells in oil and gas fields, space applications and military FOG applications. This paper will describe the relative merits of two high temperature acrylate coatings for an optical fiber designed for a FOG in such operating environments.

Results for two high temperature acrylates are presented, tested in a 200m length of loose wound fiber, coiled and supported at 75mm diameter, in line with TIA/EIA-455-192 (FOTP-192). It can be seen that both coating types give very good polarization extinction ratio (PER) performance at high temperature up to 180oC, with better performance shown by one coating type on the low temperature side, since it does not harden to the same extent below 0oC.

The long term thermal exposure effects will be discussed and experimental results presented which include testing the PER performance over temperature both before and after an extended period of high temperature endurance. This will demonstrate the relative merits of different styles of coatings. From the PER performance, the h-parameter of the fiber can be calculated and hence the preferred coating type selected and recommended for the customer operating environment.

9480-17, Session 5

Compression of quantum data using compressed sensing

Marcin Kowalski, Marek Zyczkowski, M. Karol, Military Univ. of Technology (Poland)

Current quantum key distribution systems (QKD) offer low bit rate of up to single MHz. Compared to conventional optical fiber links with multiple GHz bitrates, parameters of recent QKD systems are significantly lower.

Low bitrates of quantum systems are the result of the current state of technology as well as the physical principles of operation of distribution of a quantum key. The main technological limitation are the parameters of currently available single-photon laser sources and detectors. Currently available commercial single-photon laser sources offer the possibility of generation of single photons with the maximum repetition of 500MHz, while the maximum repetition of single-photon detectors working in this spectral range is 100MHz.

Due to the limited throughput of quantum links and because of lack of hardware techniques of eliminating problems an approach of improving data rate of QKD systems using the Compressed Sensing method for data compression is proposed. In this method, a signal (key) is multiplied with a series of filters ranked in the specific order. In order to reconstruct the signal, it is necessary to have a particular portion of the compressed signal as well as filters used for the compression. For compression purposes the filter set can be generated once and can be public.

In the article we present the conception of application of the Compressed Sensing method for compression of quantum information. The presented method is expected to give 20% increase of the throughput of data. The compression methodology as well as the signal reconstruction method and initial results of improving the throughput of quantum information link are presented.

9480-18, Session 5

A miniature turn-around for distributed temperature sensing

Xiaoguang Sun, David T. Burgess, Kyle Bedard, Jie Li, Mike Hines, OFS (United States)

In many fiber optic distributed temperature sensing (DTS) systems, a dual-ended configuration can correct the temperature measurement error associated with wavelength the dependent loss (WDL) of the optical fiber, resulting in a more accurate temperature measurement. In this configuration, two optical fibers are laid parallel to each other and connected in the distal end by a turn-around device, creating an optical path that can be interrogated bi-directionally. In many applications, where fully distributed temperature measurements are desired, tightly confined spaces limit the fiber bend diameter and thus the size of the turn-around device. In this paper we will report a miniature turn-around device measuring less than 300um in diameter and less than 2mm long. The insertion loss of the miniature turn-around is measured and will be compared with the theoretical simulations.

9480-19, Session 5

Biomimetic optical sensor for aerospace applications

Susan A. Frost, NASA Ames Research Ctr. (United States); George E. Gorospe, SGT, Inc. (United States); Cameron H. G. Wright, Steven F. Barrett, Univ. of Wyoming (United States)

We report on a fiber optic sensor based on the physiological aspects of the eye and vision-related neural layers of the common housefly (Musca domestica) that has been developed and built for aerospace applications. The intent of the research is to reproduce select features from the fly's vision system that are desirable in image processing, including high functionality in low-light and low-contrast environments, sensitivity to motion, compact size, lightweight, and low power and computation requirements. The fly uses a combination of overlapping photoreceptor responses that are well approximated by Gaussian distributions and neural superposition to detect image features, such as object motion, to a much higher degree than just the photoreceptor density would imply. The Gaussian overlap in the biomimetic sensor comes from the front-end optical design, and the neural superposition is accomplished by subsequently combining the signals using analog electronics. The fly eye sensor is being developed to perform real-time tracking of a target on a flexible aircraft wing experiencing bending and torsion loads during flight. Additionally, we are exploring how the sensor can be leveraged to improve situational awareness on unmanned aerial systems (UASs), contributing to the utilization of higher levels of automation and autonomy across the aviation system. Feasibility studies using the fly eye sensor to maintain awareness of the horizon and to sense utility wires in a scene that would otherwise be undetected by traditional cameras have been performed. We report on results of laboratory experiments using the fly eye sensor to accomplish these tasks.

9480-20, Session 6

Multicore fiber strain sensor with increased sensitivity

Amy Van Newkirk, Jose E. Antonio-López, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); Guillermo Salceda-Delgado, Ctr. de Investigaciones en Óptica, A.C. (Mexico); Mohammad Umar Piracha, FAZ Technology Research Inc. (United States); Rodrigo Amezcua-Correa, Axel Schülzgen, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

We demonstrate a strain sensor consisting of a multicore fiber (MCF) spliced between two single mode fibers (SMF). The MCF contains 7 strongly coupled single mode cores. Multiple supermodes are excited in the MCF by the SMF input, creating a multimode interference pattern in transmission, consisting of sharp spectral features with up to 45 dB resolution. Strain induces a wavelength shift of these features due to the elongation of the fiber and the change in refractive index according to the photoelastic effect. Increasing of the sensitivity is achieved through reducing the cladding diameter of the MCF, with an overall sensitivity enhancement of 7x that of a 125 ?m outer diameter MCF device, and 12x that of a standard FBG in 125 μm fiber. The maximum sensitivity achieved was about 16 nm/N of longitudinal force. The sensor has a simple design and inexpensive fabrication, consisting of only two splices between the MCF and the SMF. The splice losses are very low, less than 0.1 dB, allowing for multiplexing of multiple sensors within a single measurement chain. Additionally, this device has previously shown robust operation up to 1000 °C, making it more suitable than FBGs for extreme environment strain measurements.

9480-21, Session 6

Few-mode fiber based sensor in biomedical application

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A novel few-mode fiber based sensor for monitoring the vital signs of pulse (heart rate), and breathing rate (respiratory rate) was developed. The sensor unit consisted of a piece of few-mode fiber spliced in between two pieces of normal single mode fiber. One piece of single mode fiber was the light launching fiber. The other piece was the output fiber. Due to the fact that the stress or strain would affect the coupling between the modes in the few-mode fiber, and more than one modes existing in the few-mode fiber, the output optical power was subject to the stress or strain on the few-mode fiber and the interference between the higher order modes and the fundamental mode in the few-mode fiber. The sensor unit was applied on the wrist near the artery, and obvious heart beat signal was obtained as the strain on the few-mode fiber changed with the pulses. Three sensor units were cascaded and embedded in a chair pad to enlarge the sensing area. The pulse and breathing rate signals of the person sitting on the chair pad were obtained. Besides the pulse and breathing signals, the body movement signal was also recorded. This sensor has simple structure and is easy to fabricate. Its signal is easy to monitor and analyze. It can be used in the medical equipment in what situation non-invasive realtime monitoring and measurement of pulse rate, and respiratory/body movement pattern of healthy subjects are required (eg. MRI).

9480-22, Session 6

Fiber Bragg grating interrogation using a micro-ring resonator tunable filter with peak wavelength detection enhancement

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This work presents a demodulation technique using a silicon micro-ring resonator that extracts wavelength information from a FBG sensor. The device implements an interrogation system employing a signal processing technique that translates the peak wavelength position of a FBG spectral line into a time interval measurement. To determine the peaks, three techniques were applied. One was based on a simple maximum detection algorithm, and the other two, enhanced a detected signal by applying a finite impulse filter (FIR) and a smoothing filter. Results show an improvement of the wavelength measurement using the filtering technique compared to the maximum peak detection.

9480-23, Session 6

Nanostructured sapphire fiber for high temperature chemical sensing

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Sapphire optical fiber possesses inherent thermal and chemical stability, which makes it an excellent alternative to harsh environment sensing, where silica-based fiber is not suitable for. Development of robust cladding on sapphire fiber to impart new properties and functions has remained elusive due largely to challenges associated with suitable materials and their deposition. We present a theoretical and experimental study that explores an innovative concept of all-alumina Nanostructured Sapphire Fiber: single-crystal sapphire fiber as the waveguide core and nanoporous anodic aluminum oxide (AAO) coating with highly organized pore channels vertically aligned to the fiber surface as cladding for high temperature chemical sensing. We reveal the feasibility of Ag nanoparticles (NPs)-enabled Nanostructured Sapphire Fiber for surface-enhanced Raman scattering (SERS) sensing of 10-6 M Rhodamine 6G (R6G) after thermal treatment at 500 °C for 6 hr by taking advantage of porous AAO structure to stabilize the Ag NPs. We also conduct numerical and analytical simulation to investigate the evanescent-field interaction on AAO-cladded sapphire fiber for a group of modes, as well as the AAO porosity effect on evanescent decay for potential optimization. The development of this novel Nanostructured Sapphire Fiber sensing platform will lead to a transformative new frontier for next generation of photonic devices and sensors.

9480-24, Session 7

In-line fiber optic sensors for absolute measurement of high temperature using gas as sensing element *(Invited Paper)*

Ming Han, Univ. of Nebraska-Lincoln (United States)

All current temperature sensors, no matter electrical or optical, use some temperature-dependent properties of solid materials for sensing. These properties tend to degrade or exhibit unpredictable behaviors over extended period of time in high-temperature environment. In our technology, instead of using “solids”, the sensing material is “gas”. Specifically, we make use of the fact that the refractive index of a gas is dependent on temperature and pressure. During operation, the gas pressure in a small in-line fiber Fabry-Perot (FP) cavity is varied and the spectral shift of the FP cavity as a function of pressure is recorded. Using the slope of the spectral shift vs. pressure curve, absolute temperature can be deduced. This novel temperature method eliminates all limitations associated with solid such as nonlinearity, long-term stability, and low survivability at high-temperature. In addition, our technology has the unique capability of perform calibration free and absolute measurement of temperature, which means that the mapping of the sensor signal to temperature is independent on the sensor structure and does not require the calibration curve.

9480-25, Session 7

Optimization of detonation velocity measurements using a chirped fiber Bragg grating

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Dynamic measurements of detonation velocity profiles are performed using long Chirped Fiber Bragg Gratings (CFBGs). Such thin probes, with a diameter of typically 150 μm, are inserted directly into an explosive or simply positioned laterally. During the detonation, the width of the reflected optical spectrum is continuously reduced by the propagation of the wave-front which physically shortens the CFBG. The optical intensity reflected delivers a ramp down type of signal which is relative to the detonation velocity profile. Experimental detonation velocity measurements were completed on the side of three different high explosives (TNT, B2238 and V401) in a bare cylindrical stick configuration (diameter 2 inches, height: 10

inches). The detonation velocity range covered was 6800 to 9000 m/s. The extraction of the detonation velocity profiles requires a careful calibration of the system and of the CFBG used. A calibration procedure was developed, with the support of optical simulations, to cancel out the optical spectrum distortions from the different optical components and to determine the wavelength-position transfer function of the CFBG in a reproducible way. The 40-mm long CFBGs were positioned within the second half of the three high explosive cylinders. The excellent linearity of the computed position-time diagram confirms that the detonation was established for the three high explosives. The fitted slopes of the position-time diagram give detonation velocity values which are in very good agreement with the classical measurements obtained from discrete electrical shorting pins.

9480-26, Session 7

High electric field measurement with slab coupled optical sensors using nonlinear calibration

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Slab-coupled optical fiber sensors (SCOS) have found use in applications like testing rail-guns, Marx generators and ion-traps. These and similar applications require non-intrusiveness of electric field measurement, directional sensitivity and localization in a small region of space. SCOS technology meets the requirement of non-intrusiveness because SCOS is an all-dielectric optical fiber sensor with no metallic parts. Its operation relies on coupling light from a D-fiber into a lithium-niobate ($LiNbO_3$) slab and, since the coupling conditions depend dominantly upon the transverse component of electric field across the crystal, SCOS is directionally sensitive to a single electric field component rather than the total field magnitude. Slab dimensions are below 1 mm allowing SCOS to be fitted inside very small cavities within the system under test. High power applications, such as exist in defense or nuclear research programs, require measurement of high electric fields. For electric fields above 1 MV/m, the SCOS interrogator goes outside of linear operation mode and correct measurement calls for non-linear calibration method. While linear calibration requires knowledge of slope sensitivity at only the operating point of the interrogator, non-linear calibration requires knowledge of slope sensitivity at multiple points on the SCOS transmission spectrum. Non-linear calibration also requires information about the spectrum wavelength shift rate as a function of the applied electric field. We present measurements of electric fields up to 20 MV/m with sub-10 ns pulse rise time measured using non-linear calibration method.

9480-28, Session 8

Measurements of UV-A radiation and hazard limits from some types of outdoor lamps

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Illumination using artificial light sources is common in these days. Many manufactures are paying for the design of lamps depending on high efficacy and low UV hazards. This research is focusing on the most useable lamps in the Egyptian markets; High Pressure Mercury (HPM), Metal Halide (MH), and High Pressure Sodium (HPS). A set up for relative spectral power distribution based on single monochromator and UVA silicon detector for absolute irradiance measurements are used. The absolute irradiance in (W/m2) in UVA region of the lamps and their accompanied standard uncertainty are evaluated.

9480-29, Session 8

Real-time distributed DAS and DTS optical sensing advantages and data compression techniques for the application of hydraulic fracture monitoring

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Details are provided of the successful implementation of optical-fibre based distributed acoustic and temperature sensing (DAS & DTS) systems, for the application of real-time monitoring of hydraulic fracturing operations in an unconventional gas well.

Rayleigh based DAS and Raman based DTS interrogators were connected to standard single- and multi-mode optical fibres respectively, which were deployed along the entirety of the wellbore casing.

Results are presented for all aspects of the fracture operations, from perforation creation to fracture stage completion. Examples are provided for both successful and unsuccessful stage operations. Evidence of unsuccessful operation is provided by way of results identifying, incorrect valve operation, plug failures, and cement washout. Each of which are shown to exhibit a unique sequence of acoustic signals and thermal profiles. Evidence and effectiveness of successful stage operation is provided by way of evaluation of the frequency-domain acoustic data and warm-back evaluation of the thermal data. Detailed spectral analysis of the acoustic data further aids assessment of the relative effectiveness of the individual phases of fracture operations as a function of cluster number.

Data compression techniques, as applied to the DAS data, are presented that reduce data volumes by a factor of 7.5e6 whilst retaining pertinent signal information.

This paper thus highlights potential benefits of utilising a combination of DAS & DTS solutions 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.

9480-30, Session 8

Near-infrared absorption fiber optic sensors for ultra-sensitive CO2 detection

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IR absorption spectroscopy is widely used as a simple and reliable technique for both detection and identification of hazardous and greenhouse gases. Various mid-IR (2.5-10?m wavelength) methods that work at the highly sensitive fundamental vibration bands, such as Fourier transform IR (FT-IR) spectroscopy that detect gases through spectroscopic signatures, are available commercially. However, most commercial mid-IR spectrometers are large, expensive, and heavy tabletop instruments. On the other hand, near-infrared (NIR ~ 0.6-2.5?m wavelength) optoelectronic devices are miniaturized, low cost, and highly reliable. The biggest challenge is that most gases do not have fundamental vibration bands at NIR regions, and hence it has relatively low detection sensitivity. In this research, we present a fiber-optic sensor working at 1.57?m for CO2 detection. In order to increase the NIR absorption, we grow functional sensor materials on the surface of the core of a multimode-fiber. First, the cladding of the multimode fiber was etched away by buffered oxide etchant. Then, we used the layer-by-layer method to grow various sensor materials on the exposed core of the fiber. The fiber was then placed in a gas cell to detect CO2 absorption by mixing with nitrogen. The selected sensing layer demonstrated excellent adsorption capacity of CO2 and significantly increased the detection sensitivity down to a few hundred ppm with only 8-centimeter absorption length. The sensor also has a very rapid response time of ~10 seconds to the CO2 concentration change due to the thin film of only 100 nm.

9480-31, Session 8

A fiber optic current sensor for lightning measurement applications

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An optical-fiber sensor based on Faraday Effect is developed for measuring total lightning current. Designed for aircraft installation, it is light-weight, non-conducting, structure conforming, and is immune to electromagnetic interference, hysteresis and saturation. It can also be used on windmills, lightning towers, and can help validate lightning detection network measurements.

Faraday Effect causes light polarization to rotate when the fiber is exposed to a magnetic field in the direction of light propagation. Thus, the magnetic field strength can be determined from the light polarization change. By forming closed fiber loops and applying Ampere's law, measuring the total light rotation yields the total current enclosed. The broadband, dual-detector, reflective polarimetric scheme allows measurement of both DC component and AC waveforms with a 60 dB dynamic range.

Three sensor systems were built with different sensitivities from different laser wavelengths. The first system operates at 1310nm, uses spun polarization maintaining fiber, and can measure approximately 300 A - 300 KA. High current measurements up to 200 KA were demonstrated at a commercial lightning test facility. The system was recently installed on an aircraft and flown near icing weather conditions. Operating at 850nm, the second system uses twisted single-mode fiber and has a 150 A – 150 KA range. The third system operates at 1550nm, uses spun polarization maintaining fiber, and can measure 400 A - 400 KA. Both systems were validated with rocket-triggered lightning measurements and achieved excellent comparison results when compared to a resistive shunt.

The fiber-optic sensor provides many unique lightning measurement capabilities not possible with traditional sensors. It represents an important new tool where low-weight, large structure dimension, large total current, and low frequency capabilities are important considerations.

9480-32, Session 8

High frequency strain measurements with fiber Bragg grating sensors

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In recent years fiber Bragg grating sensors gained interest in structural health monitoring and concepts for smart structures. They are small, lightweight, and immune to electromagnetic interference. Using multiplexing techniques, several sensors can be addressed by a single fiber. Therefore, well-established structures and materials in industrial applications can be easily equipped with fiber optics sensors with marginal influence on their mechanical properties. In return, critical components can be monitored in real-time, leading to reduced maintenance intervals and a great reduction of costs. Beside of general condition monitoring, the localization of failures in a structure is a desired feature of the monitoring system. Detecting the acoustic emission of a sudden event, its place of origin can be determined by analyzing the delay time of distributed sensor signals. To achieve high localization accuracies for the detection of cracks, breaks, and impacts high sampling rates combined with the simultaneous interrogation of several fiber Bragg grating sensors are required.

In this article a fiber Bragg grating interrogator for high frequency measurements up to the megahertz range is presented. The interrogator is based on a passive wavelength to intensity conversion applying arrayed waveguide gratings. Light power fluctuations are suppressed by a differential data evaluation, leading to a reduced signal-to-noise ratio and a low strain detection limit. The measurement system is used, inter alia, to detect wire breaks in steel wire ropes for dockside cranes.

9480-33, Session 8

Fiber-optical sensors for enhanced battery safety

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Over the last years, battery safety became more and more important due to the wide spread of high-capacity Lithium ion batteries applied in e.g. consumer electronics and electrical power storages for vehicles or stationary energy storage systems. However, for these types of batteries, malfunctions could be highly dangerous and all aspects of safety issues are not sufficiently considered, yet. Therefore the improvement of the battery safety behavior is one of the most important issues discussed in present research projects.

In this paper the application of fiber-optical sensors for an enhanced battery safety is presented. The temperature is one of the most critical parameters indicating a failure of the cell, but even state-to-the-art battery management systems (BMS) are not able to monitor and interpret the distributed temperature field of a whole battery storage system sufficiently. Furthermore, the volume expansion of the battery cell, which could be monitored by the strain on the cells' surface, is one additional parameter not considered up to now. Both parameters can be simultaneously monitored by fiber optical sensor arrays, consisting of discrete fiber Bragg grating (FBG) elements. The FBG sensors are directly attached on the surface of the cell, recording the temperature as well as the strain distribution highly accurate and close mesh. Failures and malfunction such as overcharging, gassing, and thermal runaway can be early predicted and avoided to extend the battery lifetime and enhance the operational battery safety. Moreover, battery aging effects lead to variations in the volume change behavior which can be detected additionally.

Hence, a battery fully equipped with fiber optical sensor arrays in combination with an appropriate BMS enables a safe and continuous utilization of the energy storage system even under harsh conditions like rapid charging.

9480-34, Session 8

New design for a wavelength demultiplexing device

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Arrayed waveguide gratings (AWG) originally designed as demultiplexing device and manufactured with well established silicon wafer technology are already used successfully as compact spectrometers with high resolution [1].

In this paper, the concept of a new design for a wavelength demultiplexing device based on tailor-made polymers is presented. The motivation for a new design is a smaller footprint of the device and the avoidance of bended waveguides and the associated losses. Extensive simulations were performed to optimize the design. Using microscope projection lithography and hot embossing a first polymer based device was realized. Its characterization and the achieved performance in terms of resolution and covered wavelength range will be discussed.

The project is part of the German collaborative research centre "Planar Optronic Systems" (Sonderforschungsbereich, Transregio 123) funded by the DFG. The aim is to realize a sensor network in a large-scale polymer film with integrated and distributed optical sensors which partly rely on the use of a planar spectrometer.

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9480-35, Session 8

Femtosecond laser processing of evanescence field coupled waveguides in single mode glass fibers for optical 3D shape sensing and navigation

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Fiber Bragg Grating based optical shape sensing is a new and promising approach to gather position and path information in environments where classical imaging systems fail. Especially a real time in-vivo navigation of a medical catheter or endoscope without any further requirements (such as the permanent exposure to x-rays) could provide a huge advantage in countless areas in medicine.

Multicore fibers or bundles of glass fibers have been suggested for realizing such a shape sensor, but multicore fibers need a compatible connector for addressing each core separately which would have to be custom-made and glass fiber bundles are limited in their mechanical flexibility and minimum detectable bending radius.

We present the realization of a third approach. With femtosecond laser pulses local waveguides have been inscribed into the cladding of a standard single mode glass fiber. The evanescent field of the main fiber core couples to two S-shaped waveguides, which carry the light to high reflective fiber bragg gratings located 25 μm away from the centre in an orthogonal configuration. Part of the reflected light is coupled back to the fiber core and can be read out by a fiber bragg grating interrogator. A typical spectrum is presented as well as the sensor signal for bending in all directions and different radii. The entire sensor plane has an elongation of less than 5 mm and therefore enables even complicated and localized navigation applications such as medical catheters.

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9481-1, Session 1

Integration of optical functionality for image sensing through sub-wavelength geometry design *(Invited Paper)*

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Integration and pixel scaling are enabling trends for low-cost, small form-factor, light-weight, and low-power camera systems across all optical frequency bands. Integration allows on-chip implementations of optical functionalities, e.g., polarization, color and spectral selectivity, which were previously achieved using bulky external components (e.g., prisms, filter wheels). Wavelength-size pixels require focusing and guiding of light at the pixel-level (e.g., microlenses, light guides), which was not necessary for larger pixels. On-chip integration of optical functionalities and pixel-level light control is often based on miniaturized versions of conventional optical components. These components derive their functionality from material properties (e.g., absorption/reflection) or shapes (e.g., dielectric domes), but they do not lend themselves well to integration or do not scale to wavelength-size pixels. Here, I present an overview of innovative integrated optical devices that overcome the problems associated with the integration and scaling of conventional components. They are enabled by scaling of imager and focal plane array technology, and by advanced nanofabrication. Wafer-scale processing and nanofabrication have made nano-scale patterning possible, while recent discoveries regarding the optical properties of nano-patterned structures have opened up important opportunities to develop ultra-compact photonic devices. I discuss such devices showing design implementations for the visible and infrared bands, including VIS integrated color pixels in CMOS technology with geometry-based color filters, microlens functionality based on planar nano-aperture designs, and metal-based spectral filters for MWIR multispectral imaging implemented using standard nanofabrication methods. All devices are planar and ultra-thin, rely on process-compatible materials only, and derive their functionality from sub-wavelength geometry design.

9481-2, Session 1

Interaction of two nano particle plasmons for sensor application

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The area of creating artificial molecules by combining more than one nanoparticle (NP) has received significant interest recently. Similar to the way atoms join together in different combination to form all the substances in the universe, we too can make groups of new materials by combining artificial atoms or NPs1. The strong interaction of plasmon waves from different NPs can render many applications possible, including sensors2, and enhanced electro catalytic reactions3. We used an electron beam lithography process along with angle evaporation techniques to achieve nanometer-scale metallic particles with very close proximity. Gold (Au) and aluminum (Al) metal particles were chosen for the plasmonic coupling experiment because of their distinguished plasmonic behavior with peak wavelengths separated by few 100 nm. We used a variable angle ellipsometer model M-200 from J. Wolman and Company to measure change in phase difference, Δ, due to plasmonic NPs. The peak resonance wavelength for different plasmonic material was determined.

Two metallic NPs were deposited using different angles of evaporation of substrate with respect to metal crucible. We observed two peaks: one narrow plasmon peak at 525 nm showing a contribution from the Al NPs and another broad plasmon peak at 650 nm due to the Au NPs.

We have shown two-color plasmon absorption peaks due to Al and Au NPs with a nanometer-scale separation between them. The position and peak height of the coupled plasmon curves are different from the individual peaks of Al and Au NPs, respectively.

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9481-3, Session 1

CMOS compatible silicon photonics for mid-IR optical sensing

Pao T. Lin, Massachusetts Institute of Technology (United States)

CMOS compatible mid-Infrared (mid-IR) microphotonics are demonstrated using silicon on oxide undercladding pedestal waveguides as well as mid-IR transparent chalcogenide glass waveguides that monolithically integrated with a PbTe thin film photodetector. Using a pedestal undercladding geometry the optical loss for our Si waveguide is 10 dB/cm lower compared to other waveguides using planar SiO2 cladding at λ = 5 µm, and a fundamental mode is observed over a broad mid-IR spectral range. To realize a fully integrated mid-IR on-chip system, in parallel, we develop PbTe thin film detectors that can be deposited on various mid-IR platforms through a thermal evaporation technique, offering high photoresponsivity of 25 V/W from λ = 1 µm to 4 µm. Our results of low loss waveguides and integrated thin film detectors enable Si-CMOS microphotonics for mid-IR applications.

9481-4, Session 1

Development of high performance SWIR InGaAs focal plane array

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Banpil Photonics has developed a novel InGaAs based photodetector array for Short-Wave Infrared (SWIR) imaging, for the most demanding security, defense, and machine vision applications. These applications require low noise from both the detector and the readout integrated circuit arrays. In order to achieve high sensitivity, it is crucial to minimize the dark current generated by the photodiode array. This enables the sensor to function in extremely low light situations, which enables it to successfully exploit the benefits of the SWIR band. In addition to minimal dark current generation, it is essential to develop photodiode arrays with higher operating temperatures. This is critical for reducing the power consumption of the device, as less energy is spent in cooling down the focal plane array (in order to reduce the dark current).

We at Banpil Photonics are designing, simulating, fabricating and testing 640 x 512 SWIR InGaAs arrays with 15 micron pitch, and have achieved low dark current density at room temperature. This paper describes Banpil's development of the photodetector array. We also highlight the fabrication technique used to reduce the amount of dark current generated by the photodiode array, in particular the surface leakage current. This technique

involves the deposition of strongly negatively doped semiconductor material in the area between the pixels. This process reduces the number of dangling bonds present on the edges of each pixel, which prevents electrons from being swept across the surface of the pixels. This in turn drastically reduces the amount of surface leakage current at each pixel, which is a major contributor towards the total dark current. We also present the characterization data and analysis that illustrates the dark current mechanisms, and also discuss the improvements of our array over other available devices. Also highlighted are the challenges and potential opportunities for further reduction of dark current, while maintaining other parameters of the photodiode array, such as size, weight, temperature of peak performance (lowest dark current), and power consumption. Finally, a brief overview of emerging military, commercial, and industrial applications that will benefit from this high performance InGaAs photodiode array is presented.

9481-5, Session 1

Functionalized fluorescent silver nanoparticle surfaces for novel sensing and imaging techniques

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A deposition technique has been developed to create thin metal surfaces composed of functionalized fluorescent silver nanoparticles on top of glass or plastic substrates. Deposition is controlled through excitation of nanoparticles via a confocal microscope, allowing for rapid surface formation, high resolution patterning and convenient imaging. No significant photobleaching of these fluorescent structures was observed during continuous excitation experiments, which lasted over three minutes. The wavelength of the laser which drives the deposition is close to the surface plasmon resonance (SPR) wavelength of the nanoparticles, highlighting the crucial role of an induced dipole moment in the nanoparticles. This SPR enhancement was confirmed through total internal reflection fluorescence microscopy and has not previously been reported. Longer wavelength lasers did not cause sizeable deposition of these nanoparticles, which shows the size dependence of their SPR wavelength, ultimately allowing for the selective placement of different sized particles based on the deposition laser line selected. Fluorescent microstructure assemble can be achieved in less than one minute and precise control of the deposition area is possible. The functionalization of these nanoparticles can be tailored to a desired application and no substrate pretreatment or modification is necessary. Sensing and imaging techniques which employ fluorescent nanoparticle deposits with customizable surface functionality can be conceived. Initial investigations have demonstrated that surfaces can be designed to mimic the glucan and mannan layers of a fungal cell wall. This surface functionality will allow for the study of immune cell response and interaction with these fungal cell wall mimics. Other possible applications which will be commented on include but are not limited to; sensing and imaging of membrane curvature through confocal and TIRF microscopy, study of the cellular up take of fluorescent nanoparticles and the molecules of their functionalized surfaces, investigations into the effect of changing dielectric environments on properties of fluorescent structures and studying cellular interactions with these surfaces.

9481-6, Session 1

SWIR photodetector development at Fraunhofer IAF

Frank Rutz, Philipp Kleinow, Rolf Aidam, Matthias Wauro, Lutz Kirste, Wolfgang Bronner, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany); Alexander Sieck, AIM INFRAROT-MODULE GmbH (Germany); Martin Walther, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany)

For surveillance and reconnaissance applications in the short-wave infrared (SWIR) spectral range, the imaging systems have to cope with usually very low photon flux densities. Thus, dark-current and noise characteristics of the focal plane array (FPA) are demanding. On the other hand, the challenge of detecting extremely low photocurrents can be mitigated by utilizing an internal gain as provided by avalanche photodiodes (APDs).

Fraunhofer IAF has recently started the development of InGaAs-based SWIR detectors. We report on the current development status covering design considerations, epitaxy, process technology and electro-optical characterization. Detector structures based on both, classical InGaAs PIN homojunction diodes as well as InGaAs/InAlAs APDs in separated-absorption-grading-charge-and-multiplication layer heterostructures, have been grown by molecular beam epitaxy on InP. Diodes structures were fabricated with a dry-etch mesa process and a subsequent dielectric passivation of the mesa sidewalls. High-resolution FPAs with 640 x 512 pixels and a 15 µm pixel pitch based on PIN diodes have been assembled to a camera test setup in cooperation with AIM Infrarot-Module GmbH. Design variations, in particular for the APDs, were assisted by band-edge-profile simulations. APD test structures as well as fan-out hybrids have been characterized, revealing gain values larger 300 at room temperature.

9481-7, Session 2

UV/VIS/NIR imaging technologies: challenges and opportunities *(Invited Paper)*

Rihito Kuroda, Shigetoshi Sugawa, Tohoku Univ. (Japan)

No Abstract Available

9481-8, Session 2

InAs1-xSbx nanopillar photodetectors on GaAs (111)b substrates

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In this talk I will overview the growth, fabrication and characterization of InAsSb nanopillar photodetectors on GaAs (111) B substrates. Fully relaxed InAs buffer layers were grown by MBE on GaAs substrates followed by InAsSb nanopillars grown by MOCVD. Both the InAs epi layer and InAsSb nanopillar were characterized by photoluminesce measurements. Front side illuminated photodetectors were fabricated and characterized using FTIR spectral measurements and temperature dependent current voltage measurments.

9481-9, Session 2

Improved optical resonance in mid-infrared GaAs-based modulating retro-reflectors

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In this work, we studied a mid-infrared modulating retro-reflector (MRR) design that is GaAs-based because of the flexibility to monolithically

incorporate reflective optics along with quantum well modulator region. Using solid-source molecular beam epitaxy, we produced MRR devices where the GaAs quantum well(s) in the modulator region contained AlGaAs barriers to tune the wavelength selectivity beyond three microns. The width of the quantum well was also adjusted in order to achieve free electron absorption within the confined energy subbands, and modified by way of the quantum confined Stark effect. When the applied electric field varies in polarity, intensity, or frequency, the fabricated MRRs behave as an optional shutter--absorbing or transmitting the incident wavelength(s) energy dependent on the applied field. Our work shows that the ability for the mid-infrared modulating region to effectively act as a shutter device depends on the number of cascading quantum wells, though increasing the number of wells directly increases the overall thickness of the modulating region and adversely affects the reflected power of the mid-infrared modulated beam. The shutter operation was achieved by applying an alternating square bias across the QWM region, and the speed at which the quantum wells switch from absorbing to non-absorbing was dependent on the physical size of the device. Increasing the physical size increases the associated device capacitance. The maximum achievable contrast ratio for these devices is calculated to be 1.6:1 for applied voltages between 12V and 25 V.

9481-10, Session 2

Germanium/zinc sulfite distributed Bragg reflectors for large size MOEMS Fabry-Perot interferometers

Julian L. Chee, EPIR Technologies, Inc. (United States); Neelam Gupta, U.S. Army Research Lab. (United States); Silviu Velicu, EPIR Technologies, Inc. (United States)

Commercial Micro Opto-Electro-Mechanical System (MOEMS) Fabry-Perot Interferometer (FPI) devices are currently available for single element (SE) infrared photo detectors (IR-PD) devices. Existing FPI designs are between 500 µm by 500 ?m to 2 mm by 2 mm in size to satisfy 30 ?m by 30 ?m square to 500 µm by 500 ?m IR-PD filtering requirements. With the growing trend of hyperspectral thermal imaging and chemical detection using IR focal plane arrays (FPAs), the planar mirror size of MOEMS FPI must scale upwards to 12 mm by 12 mm square to ensure full coverage for 9.6 mm x 7.7 mm sized (640 x 512 format, 15 ?m pitch) FPAs. In this paper, we present the process metrology and infrared (IR) transmissivity of our large size germanium/zinc sulfite dielectric Bragg mirror for short-, mid-, and long wavelengths filtering. We deposit the dielectric stacks in various 2N+1 combination using our shadow mask deposition technique which enables us to bypass the need to perform post-deposition chemical etching. This paper will describe the principle of the shadow mask deposition technique and the fabrication process. We will characterize and report the surface roughness1 of both germanium and zinc sulfite, which will provide a numerical value for the thickness of the dielectric interface layer. The residual stress of each dielectric layer will also be measured, which will lead up to quantifying the radius of curvature of the final Bragg mirror.

9481-11, Session 2

High NA, VIS+IR, and athermal low-light camera objective

Markus Lipp, Frank Saupe, Matthias Falk, Martin Forrer, FISBA OPTIK AG (Switzerland)

Low-light cameras are an important tool e.g. for defense, security, and sensing applications. Specialized sensors are commercially available. However, the challenge is to design a lens system that meets three important conditions at the same time: high NA for maximum speed (f#<1.25), broadband color correction from VIS to NIR (400-1100 nm), and a passively athermal design suitable within the typical defense temperature range, i.e. minimal shift of the focal length and no degradation of the MTF. The entire design makes the lens compact and robust with low weight.

The passive athermalization does not need any active readjustment of the sensor, but uses a passive thermal compensation benefiting from tailored materials for spacers and housing as well as an optimization of the choice of the glass materials for the lens elements. The optical design uses spherical and aspherical lens elements to maximize the MTF over a large field. Several techniques are used to reduce crucial centering errors including a radial compensator unit. A special thermal chamber has been built that allows automated measurements in a commercially available MTF measurement device at various temperatures. FISBA has designed and produced such a lens system and MTF measurements for the entire wavelength range at various temperatures will be presented as well as other performance data.

9481-12, Session 3

Image sensor conversion gain determination in data constrained environment: blending temporal and spatial information for a mean-variance measurement

Blake C. Jacquot, Sean Maguire, Brett Bolla, The Aerospace Corp. (United States)

This paper presents a hybrid technique for measuring conversion gain that blends spatial and temporal information, allowing users to quickly arrive at an accurate conversion gain with little knowledge of sensor defects. It blends single pixel methods with multiple pixel methods. We present measured data from a visible CMOS image sensor using three methods: single pixel, multiple pixel, and hybrid method. Additionally, we provide statistical reasoning arguing for validity of the hybrid method. To our knowledge, this is the first report of this hybrid technique.

Conversion gain (e-/DN) directly relates measured digital numbers (DN) to input-referred electrons (e-) for the unit cell of an image sensor. Conversion gain can be directly measured by considering the sensor under varying illumination levels in coordination with Poisson statistics. Typically, there are two approaches: measure a single pixel over time or measure a group of pixels at one point in time after correcting for gain non-uniformity. The plotted statistics from these measurements are typically called either mean-variance or photon-transfer curves. The measurement of a single pixel is relatively straightforward and requires collection of many consecutive frames in order to get meaningful statistics not dominated by noise of the measurement. The data volume for an accurate single-pixel measurement can become unwieldy. In contrast, the measurement of a group of pixels requires fewer consecutive frames, but unfortunately requires non-uniformity adjustments to correctly calculate statistics. This adjustment requires considerable judgment on the part of the analyst and will yield poor results if applied incorrectly.

9481-13, Session 3

Advanced computational sensors technology

Charbel G. Rizk, Johns Hopkins Univ. Applied Physics Lab., LLC (United States)

The Advanced Computational Sensors Team at JHU APL and ECE has been developing advanced readout integrated circuits (ROIC) technology for over 10 years with a particular focus on the key challenges: dynamic range, sampling rate, system interface and bandwidth, and detector materials or band dependencies. Because the pixel array offers parallel sampling by default, the team successfully demonstrated that adding smarts in the pixel and the chip can increase performance significantly. Each pixel becomes a smart sensor and can operate independently in collecting, processing and sharing data. In addition, building on the digital circuit revolution, the effective well size can be increased by orders of magnitude within the same pixel pitch over analog designs. This research has yielded an innovative

class of a system-on-chip concept: the Flexible Readout and Integration Sensor (FRIS). All key parameters are programmable and/or can be adjusted dynamically. The following functionality has been demonstrated:

- Pixel level A/D conversion
- Pixel level NUC (gain and offset)
- Background level
- Pixel management (disabling pixels, local/global reset)
- Individual pixel and non-contiguous sub-array addressability
- Very large effective well depth (up to 26 bits)
- Variable LSB equivalent in e, from ~1e up to the integrating capacitor
- Auto detection, only pixels or regions of interest (e.g. targets) are readout
- High sampling rate (50+ KHz) without windowing
- Potentially detectors, wavelength, and polarity agnostic
- Active and passive imaging

Another aspect of this promising technology is the ability to support ranging on selected targets in the scene with a pulsed laser. Such capability is likely to allow an improved SWaP-C solution for imaging and ranging systems.

This paper reports on the latest development and testing for 1-color (either polarity) and 2-color applications and one vertically integrated design using TSV's. One prototype, with the most on-chip functionality, has been demonstrated with visible and LWIR and is currently being evaluated for SWIR and extended SWIR.

9481-14, Session 3

360-degree scanning light scattering profiler (SLSP) to quantitatively characterize the front and back light scattering from intraocular lenses (IOLs)

Bennett N. Walker, Robert H. James, Don Calogero M.D., 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. As a result, new IOL designs are constantly emerging with modified components, materials, and functionalities. Each modification made has the potential to impact the light-surface interactions that potentially lead to an increase or decrease of front and back scattered light, resulting in various unwanted negative effects (e.g. halos, glistenings and glare). For example, the introduction of multifocal IOLs (MIOLs) has resulted in an increase of patients reporting halos and glare, particularly when driving at night. To help avoid implanting IOLs prone to unwanted light scattering, preclinical studies can be conducted to better evaluate these effects. Recently, we have introduced a novel Scanning Light Scattering Profiler (SLSP) to quantitatively observe IOL light scattering patterns with a 360-degree view. If a correlation between these preclinical studies can be made with clinically reported incidences, IOLs that are prone to produce unwanted light scattering can be identified before implantation occurs. In addition, by manipulating the wavelength of light, laser beam profile, and angle of incidence a better understanding of the environment that causes problematic scattering of light can be achieved, potentially leading to better IOL designs that minimize unwanted glare. These studies, as well as others, can significantly improve the proficiency of preclinical evaluations of IOL safety and efficacy which can ultimately improve the health of millions of Americans every year.

9481-15, Session 3

The application of machine learning in multi sensor data fusion for activity recognition in mobile device space

Asmaa H. Marhoubi, Sara Saravi, Eran A. Edirisinghe, Loughborough Univ. (United Kingdom)

The present generation of mobile handheld devices come equipped with a large number of sensors. The key sensors include the Ambient Light Sensor, Proximity Sensor, Gyroscope, Compass and the Accelerometer. Many mobile applications are driven based on the readings obtained from either one or two of these sensors. However the presence of multiple-sensors will enable the determination of more detailed activities that are carried out by the user of a mobile device, thus enabling smarter mobile applications to be developed that responds more appropriately to user behaviour and device usage. In the proposed research we use recent advances in machine learning to fuse together the data obtained from all key sensors of a mobile device. We propose the use of bagging and ensemble classifier based approaches to identify a mobile device's behaviour in the space it is present. Feature selection algorithms are used to remove non-discriminant features that often lead to poor classifier performance. As the sensor readings are noisy and include a significant proportion of missing values and outliers, we use machine learning based approaches to clean the raw data obtained from the sensors, before use. Based on selected practical case studies, we demonstrate the ability to accurately recognise device behaviour based on multi-sensor data. Accuracy values of above 0.95 measured in terms of a R-squared test is reported.

9481-16, Session 4

Uncooled LWIR imaging: applications and market analysis *(Invited Paper)*

Satomi Takasawa, Techno Systems Research Co., Ltd. (Japan)

Uncooled Long-Wave Infrared (LWIR) Imaging Market is changing dynamically due to its prospective dual applications in both commercial and defense sectors. Manufacturers have been deploying practical strategies to expand its common footprint in the consumer market. Although the volume of the existing markets especially in scientific and security sectors have been about 300 thousand pcs worldwide and limited so far. However, automotive night vision, mainly in Europe, has now become a promising new market for thermal cameras and the market is expected to expand from around 2018 by entering into mass production phase. In recent year, besides this trend, some distinct actions to approach to the volume market have been taken by several manufacturer, especially introducing consumer products such as smartphone add-on cameras , and Smart Building projects for energy management. These actions are to promote an economy of scale and aim to increase the market size.

Reviewing overall LWIR applications and their markets, this is the time for all manufacturers, including component suppliers such as image sensors and lenses, to determine a strategy towards a market expansion phase from around 2017 and carry it into action. For example, there are still many challenges to be overcome to enter into new applications, including making small-form factor module, cost reduction etc. We conceive that there can be more technological innovations in material and more chances for new entries. In this presentation, uncooled LWIR Imaging applications and their market trends especially in consumer sector, and the major components market trends will be addressed.

9481-17, Session 4

Advanced illumination control algorithm for medical endoscopy applications

Ricardo M. Sousa, AWAIBA Lda. (Portugal) and Univ. da Madeira (Portugal); Martin Wäny, Pedro Santos, AWAIBA Lda. (Portugal); Morgado Dias, Univ. da Madeira (Portugal) and Madeira Interactive Technologies Institute (Portugal)

CMOS image sensor manufacturer, AWAIBA, is providing the world's smallest digital camera modules to the world market for minimally invasive surgery and one time use endoscopic equipment. Based on the world's smallest digital camera head and the evaluation board provided to it, the aim of this paper is to demonstrate an advanced fast response dynamic control algorithm of the illumination LED source coupled to the camera head, over the LED drivers embedded on the evaluation board. Cost efficient and small size endoscopic camera modules nowadays embed minimal size image sensors capable of not only adjusting gain and exposure time but also LED illumination with adjustable illumination power. The LED illumination power has to be dynamically adjusted while navigating the endoscope over changing illumination conditions of several orders of magnitude within fractions of the second to guarantee a smooth viewing experience.

The algorithm is centered on the pixel analysis of selected ROIs enabling it to dynamically adjust the illumination intensity based on the measured pixel saturation level. The control core was developed in VHDL and tested in a laboratory environment over changing light conditions. The obtained results show that it is capable of achieving correction speeds under 1 s while maintaining a static error below 3% relative to the total number of pixels on the image. The result of this work will allow the integration of millimeter sized high brightness LED sources on minimal form factor cameras enabling its use in endoscopic surgical robotic or micro invasive surgery.

9481-18, Session 4

How thermographic mapping can help with enhanced oil recovery

Eric Olsen, Aerial Thermal Imaging (United States)

Today, oil companies are using our technology to understand more about the overburden and sealing rock that can allow steam to make its way towards the surface. When cyclic steam stimulation occurs, subsidence can weaken the ground, creating the possibility of sinkholes or blowouts. We assist oil companies by monitoring their grounds and infrastructure thermographically, thereby helping provide safety and efficiency data.

Our thermographic maps are more commonly known as deliverables. A deliverable often is made of thousands of individual thermal images. Every single image in a survey that makes a complete deliverable is georeferenced and orthorectified. Individual images are stored in an enhanced GeoTiff format containing GPS data, aircraft yaw, pitch and roll data, and radiometric temperature data. This data is used to complete the deliverable, translating it into a thermographic map in terms of a visual color gradient representing temperature intensity and radiometric temperature, where every pixel contains temperature data.

When we think of thermal imaging, we think of multiple colors or black and white palettes representing intensity of a surface temperature. Often, important aspects of a deliverable can go unseen. We now have two major advances in the development of the new technology. The first is providing users the ability to see a grand view of the oil field without false visual data stemming from contrasting artifacts. We achieve this with our global contrasting software. This grand view is created by multiple images to be globally contrasted without altering the radiometric or thermal data.

The second major advance is the ability to use radiometric data collected by the infrared detector and ground placed data loggers to increase ground temperature accuracy, and then implement that data into GIS, georeferenced or orthorectified deliverables.

We have developed a process and method of monitoring surface thermal expression intensity and trending. MapTemp software was created by Aerial Thermal Imaging to solve a problem with the way users are able to understand and interpret deliverables. The basic operation of MapTemp is to allow users to instantly know the actual temperature and GPS location of a deliverable at the click of a mouse. This includes users who have no GIS skills. Users are able to select a temperature range, such as temperatures between 70F as low to 90F as high, then highlight just that area with the colors red as maximum temperature and blue as minimum temperatures.

Gradients are applied to the high and low to allow users to focus on the range of highlighted temperatures. A specific surface thermal expression can be located on the deliverable and the user can zoom in for more details. Once the user has found an area of interest, software tools can then be implemented.

9481-19, Session 4

Information content capabilities of very high resolution optical space imagery for updating GIS database

Mehmet Alkan, Yildiz Technical Univ. (Turkey); Karsten Jacobsen, Leibniz Univ. Hannover (Germany)

Nowadays, the number and capacity of very high resolution optical satellites grows permanently, so the access to very high resolution space images is not any more a problem. The use of Geographic Information Systems (GISs) together with Remote Sensing became important. With the increased ground resolution a competition to aerial images exist. For the generation of topographic maps, today available as GIS, the accuracy and the information content - what elements can be identified in the image - are important. Both may limit the presentation scale of topographic maps. As horizontal accuracy 0.25mm up to 0.3mm in the map scale are accepted. The required information content is more complicate. The object details to be presented in topographic maps vary from area to area which is based on the planned and unplanned areas. In this study, images from IRS-1C, Kompsat-1, SPOT 5, OrbView-3, IKONOS, QuickBird and WorldView-1 have been used for topographic mapping. For this reason, Zonguldak test field is an important area for applications of the high resolution imageries. The details which can be identified in the space images dominantly depends upon the ground resolution, available as ground sampling distance (GSD). In this study, high resolution imageries have been tested depending on the GSD and corresponding to the map scales for updating GIS database.

9481-20, Session PThu

Aliasing removing of hyperspectral image based on fractal structure matching

Ran Wei, Ye Zhang, Junping Zhang, Harbin Institute of Technology (China)

Due to the richness on high frequency components, hyperspectral image (HSI) is more sensitive to distortion like aliasing. Many methods aiming at removing such distortion have been proposed. However, seldom of them are suitable to HSI, due to low spatial resolution characteristic of HSI. Fortunately, HSI contains plentiful spectral information, which can be exploited to overcome such difficulties. Motivated by this, we proposed an aliasing removing method for HSI. The major differences between proposed and current methods is that proposed algorithm is able to utilize fractal structure information, thus the dilemma originated from low-resolution of HSI is solved. Experiments on real HSI data demonstrated subjectively and objectively that proposed method can not only remove annoying visual effect brought by aliasing, but also recover more high frequency component.

9481-21, Session PThu

A low noise low power 512x256 ROIC for extended wavelength InGaAs FPA

SongLei Huang, Shanghai Institute of Technical Physics (China)

A low noise low power 512x256 readout integrated circuit (ROIC) based on Capacitance Trans-impedance Amplifier (CTIA) was designed in this paper. The ROIC with 30μm pixel-pitch and conventional 72 fF integrated capacitance and test structure capacitance from 5 to 60 fF, was fabricated in 0.5μm DPTM CMOS process. The results showed that output voltage was 2.0V and power consumption was about 150mW, conventional output noise was about 3.6E-4V which equivalent readout noise was 160e-, and the test structure noise was from 20e- to 140 e-. Through the comparison of readout noises in Integration Then Readout (ITR) mode and Integration While Readout (IWR) mode, it indicated that in IWR mode, readout noise comes mainly from both integration capacitance and sampling capacitance, while in ITR mode, readout noise comes mostly from sampling capacitance. Finally the ROIC was flip-chip bonded with Indium bumps to extended wavelength InGaAs detectors with cutoff wavelength 2.5μm at 200K. The peak detectivity exceeded 5E11cmHz1/2/w with 72nA/cm2 dark current density at 200K.

9481-22, Session PThu

A telephoto camera system with shooting direction control by gaze detection

Daiki Teraya, Takumi Hachisu, Tomohiro Yendo, Nagaoka Univ. of Technology (Japan)

For safe driving, it is important for driver to check traffic conditions such as traffic lights, or traffic signs as early as soon.

If on-vehicle camera takes image of important objects to understand traffic conditions from long distance and shows these to driver, driver can understand traffic conditions earlier.

To take image of long distance objects clearly, the focal length of camera must be long.

When the focal length is long, on-vehicle camera doesn't have enough field of view to check traffic conditions.

Therefore, in order to get necessary images from long distance, camera must have long-focal length and controllability of shooting direction.

In previous study, driver indicates shooting direction on displayed image taken by a wide-angle camera, a direction controllable camera takes telescopic image, and displays these to driver.

However, driver uses a touch panel to indicate the shooting direction in previous study. It is cause of disturb driving.

So, we propose a telephoto camera system for driving support whose shooting direction is controlled by driver's gaze to avoid disturbing drive.

This proposed system is composed of a gaze detector and an active telephoto camera whose shooting direction is controlled.

We adopt non-wear detecting method to avoid hindrance to drive.

The gaze detector measures driver's gaze by image processing.

The shooting direction of the active telephoto camera is controlled by galvanometer scanners and the direction can be switched within a few milliseconds.

We confirmed that the proposed system takes images of ahead of subject's gaze by experiments.

9481-23, Session PThu

Reconstruction the system PSF by using the sub pixel technique

Xiaofeng Su, Fansheng Chen, Shanghai Institute of Technical Physics (China)

Point spread function (PSF) is a very important indicator of the imaging system; it can describe the filtering characteristics of the imaging system. The image is fuzzy when the PSF is not very well and vice versa. In the remote sensing image process, the image could be restored by using the PSF of the image system to get a clearer picture. So to measure the PSF of the system is very necessary. Usually we can use the knife edge method, line spread function (LSF) method and streak plate method to get the modulation transfer function (MTF), and then use the relationship of the parameters to calculate the PSF of the system. In the knife edge method, the non uniformity (NU) of the detector would lead an unstable precision of the edge angle; using the streak plate could get a more stable MTF, but it is only at one frequency point in one direction, so it is not very helpful to get a high-precision PSF. In this paper, we measured the impulse response directly by using the image of the point target and combined with the energy concentration to calculate the PSF. First we made a point matrix target board and make sure the point can image to a sub pixel position at the detector array; then we used the centre of gravity to locate the point targets image to get the energy concentration; then we fusion the targets image together by using the characteristics of sub pixel and got a stable PSF of the system. Finally we used the simulation results to confirm the accuracy of the method.

9481-24, Session PThu

A bionic multi-band polarimetric imaging system

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Multi-band polarimetric imaging technology can be applied in many fields such as classification, target detection, 3-D surface reconstruction, glare and shadow removing [1][2]. However, conventional multi-band polarimetric imaging technologies are based on dispersion, beam split or interference to obtain spectral information. Polarimetric information is measured by rotating polarizer. It can not capture image of large field of view (FOV) fast.

The researches on biology show that some aquatic organisms (e.g., mantis shrimp) have multi-band polarimetric vision. The FOV of their compounds is nearly 360°, each ommatidium sense information of one spectral band or polarimetric angle in a parallel way [3][4]. In this paper, based on the analysis of the spectral and polarimetric sensing mechanism of mantis shrimp, a bionic isomeric multi-band polarimetric vision model is built. Images of different spectral bands or polarimetric angles are captured by different ommatidia, after the information processing, multi-band polarimetric image of large FOV can be reconstructed. Then we establish bionic multi-band polarimetric imaging system using camera array. There are nine CCDs in the proposed imaging system, they are arranged by 3?3 in rectangle. Polarizer of different angles (0°, 45°, 90° and 135°) and spectral filters of different bands (red, green, blue, yellow and orange) are fixed before the lens. The disparity between the viewing angles of each component camera leads to information loss in the expanded FOV. By exploiting the redundancy and correlation (RAC) of images among different bands and angles [5][6], we estimate the missing information using the low-rank matrix recovery method. The FOV and size of the reconstructed image are greater than those of the images captured using single CCD camera.

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9481-25, Session PThu

Imaging by electromagnetic induction with resonant circuits

Roberta Guilizzoni, UCL (United Kingdom); Joseph Watson, AWE (United Kingdom); Paul Bartlett, Ferruccio Renzoni, UCL (United Kingdom)

2D imaging of metallic samples by means of resonant frequency measurements has been demonstrated. The experiment is based on a resonating system made up of a coil connected to a capacitor bank to form a parallel LCR circuit. The presence of a metallic object produces a change in the parameters of the equivalent LCR circuit with respect to the values of the system in air. The change in the system resonant frequency and Q-factor was measured by means of an impedance analyser. Two imaging techniques based on position-resolved measurements of the resonant frequency and the Q-factor, respectively, were developed and compared. Squared and circular samples (1-2 mm thickness) made of metals having different values of electrical conductivity and magnetic permeability were coupled to cylindrical shaped ferrite-cored coils and air-cored coils. The position of each metallic sample was controlled by an XY stage. A position scan was performed by moving the sample to be imaged on a plane which was parallel to the plane of the coil. The resonant frequency and the Q-factor values were measured at each position of the scan. Both the developed techniques allowed imaging of different metallic samples. In particular, the imaging technique based on Q-factor measurements successfully distinguished between samples with different conductivity.

9481-26, Session PThu

Enhancing the quality of experience of a portable device by creating an illumination model based on the ambient light sensor readings

Asmaa H. Marhoubi, Helmut E. Bez, Eran A. Edirisinghe, Sara Saravi, Loughborough Univ. (United Kingdom)

The present generation of Ambient Light Sensors (ALS) of a mobile handheld device suffer from two practical shortcomings. The ALSs are narrow angle, i.e. they respond effectively only within a narrow angle of operation and there is a latency of operation. As a result mobile applications that operate based on the ALS readings could perform sub-optimally especially when operated in environments with non-uniform illumination. The applications will either adopt with unacceptable levels of latency or/and may demonstrate a discrete nature of operation. In this paper we propose a framework to predict the ambient illumination of an environment in which a mobile device is present. The predictions are based on an illumination model that is developed based on a small number of readings taken during an application calibration stage. We use a machine learning based approach in developing the models. Five different regression models were developed, implemented and compared based on Polynomial, Gaussian, Sum of Sine, Fourier and Smoothing Spline functions. Approaches to remove noisy data, missing values and outliers were used prior to the modelling stage to remove their negative effects on modelling. The prediction accuracy for all models were found to be above 0.99 when measured using R-Squared test with the best performance being from Smoothing Spline. In this paper we will discuss mathematical complexity of each model and investigate how to make compromises in finding the best model.

9481-27, Session PThu

Surface plasmon resonance (SPR) in a chemically etched ZnSe substrate and its effect on the Raman signal enhancement

Syed K Islam, City College, City University of New York (CUNY) (United States); John Lombardi, Maria Tamargo, Richard Moug, The City College of New York (United States)

The proximity of a metal nanoparticle to a molecule has been found to considerably enhance the Raman intensity by factors in the range of 10^6 to 10^12. This phenomenon, known as surface-enhanced Raman spectroscopy (SERS), has been shown to be caused by several resonances in the molecule-metal system, including the surface plasmon of the metal conduction band, molecular resonances, as well as charge-transfer resonance between the molecule and nanoparticle. In semiconductors, according to Mie scattering theory, the plasmon resonance which lies in the visible region of the spectrum originates in the valence band when the particle size is adjusted to be on the order of 100-200 nm. This resonance in conjunction with charge transfer, molecular resonance and an additional exciton resonance are responsible for large enhancements observed in semiconductors.

We report the observation of surface-enhanced Raman scattering (SERS) from a chemically etched ZnSe surface using 4-mercaptopyridine (4-MPy) as probe molecules. A thin film of ZnSe is grown by molecular beam epitaxy (MBE) and then etched using a strong acid. A layer of hemi-ellipsoidal nanoparticles is obtained on the surface. Using the results of the Mie theory, we controlled the size of the nanoparticles to overlap significantly with maximum efficiency of near-field plasmon enhancement. Our Raman spectra show an enhancement factor of (2x10^6) of the intensity of 4-MPy normal modes when 4-Mpy molecules are adsorbed on the surface using a 514.5 nm laser for excitation. We believe this large enhancement factor is an indication of the coupled contribution of several resonances. We propose that some combination of surface plasmon, charge transfer, band gap resonances are most likely the contributing factors in the observed Raman signal enhancement, since all three of these resonances lie close to the excitation wavelength. Future research involves designing different type semiconductor nanoparticles using the Mie theory and exploring the application of surface plasmons in semiconductor SERS.

9481-28, Session PThu

Effect of high energy proton implantation on the device characteristics of InAlGaAs-capped InGaAs/GaAs quantum dot based infrared photodetectors

Sourabh Upadhyay, Arjun Mandal, Hemant J. Ghadi, Dinesh Pal, Indian Institute of Technology Bombay (India); Nagaraju B. V. Subrahmanyam, Pitamber Singh, Bhabha Atomic Research Ctr. (India); Subhananda Chakrabarti, Indian Institute of Technology Bombay (India)

Self-assembled In(Ga)As/GaAs based quantum dot infrared photodetectors (QDIPs) have shown promise for military, medical diagnosis etc. applications. In this report, we are studying the effect of proton implantation on QDIP device heterostructure with variable fluence, with an idea to passivate defects and trap levels present in the active region, inorder to

reduce the dark current. A 10-layer QDIP structures were grown by solid state molecular beam epitaxy, with each layer consisting of 7 Monolayer (ML) In0.5Ga0.5As QDs along with a combination of 30Å quaternary (In0.21Al0.21Ga0.58As) and 500Å GaAs capping. To investigate effect of implantation on device performance, the heterostructures were further implanted with 3 MeV protons with varying fluence between 2.0 x 1012 to 1.0 x 1013 ions/cm2 (A- asgrown, B-2.0 x 1012 , C-4.0 x 1012, D-6.0 x 1012, E-8.0 x 1012 and F-1.0 x 1013). Single pixel detectors were fabricated by using two step photolithography, wet etching and metal evaporation technique. Minimum dark current density at 77K with -0.75V applied bias was observed in device F(2.0 x 10-7 A/cm2) which was almost 3 order lower than the asgrown device sample (7.0 x 10 -4 A/ cm2) indicating improvement in device performance with implantation. Implantation results in suppression of field assisted tunneling process of carriers, and so compared to an asgrown sample others exhibited lower dark current densities. All the devices at 77K exhibited multi-color spectral responses with peak wavelength around 7.0 and 5.5 μm. At 77 K, increment in peak detectivity (D*) up to two orders of magnitude from 3.9 x108 to 1.0 x 1010 cm-Hz1/2/W was obtained from the implanted devices at a bias of -1.6 V . This is probably the first report in which high energy proton implantations is proven to enhance QDIP performances. DST, India and Riber are acknowledged.

9481-29, Session PThu

A detail investigation on quaternary and ternary capped strain coupled quantum dots based infrared photodetectors and effect of rapid thermal annealing temperature

Subhananda Chakrabarti, Hemant J. Ghadi, Sourav Adhikary, Saikalash Shetty, Akshay Balgarkashi, Indian Institute of Technology Bombay (India)

Quantum dot infrared photodetector (QDIP) based thermal cameras have various applications in the field of military, astronomy and medical science. Though researches use this technology widely from last decade, but it suffers certain disadvantages like reduced absorption co-efficient and in-homogeneities in dot size distribution. To overcome the above disadvantages multilayer stacking of coupled quantum dots (QD) are used. In multilayer stacking elastic strain propagating from underlying layers will result in uniform dot size distribution with a possibility of achieving higher device efficiency. In this report, we are comparing two different QDIP architectures capped with quaternary and ternary layer of different barrier thicknesses and effect of rapid thermal annealing on the device performances. In these heterostructures, fixed quaternary and ternary capping of 3 nm and varying GaAs thickness from 12-18 nm is used (Quaternary device Q1, Q2, Q3 and Q4 and similarly ternary T1, T2, T3 and T4 with 12, 15, 18 and 21 nm respectively). Low temperature power dependent PL spectra exhibit a multimodal distribution of the QDs in all the heterostructures which has been confirmed by XTEM. High thermal stability upto 800°C i.e. minimum PL peak shift in terms of wavelength was observed in all quaternary coupled devices with annealing compared to ternary (it was up to 700°C) capped QDIP. The vertical strain propagating from underlying QDs prevents the inter-diffusion by maintaining a strain relaxed state. Minimum Dark current density was observed in quaternary capped QDIP (Q2) and one order enhancement in detectivity compared to ternary. Q1 was most red shifted with peak spectral response observed at 7.3 μm and compared to ternary all quaternary devices showed narrow spectrum with less than 20% spectral line-width. Q2 was annealed and devices were fabricated using 2 step lithography process. For 750°C annealed a maximum operating temperature of 140K with 5 times increase in photocurrent compared to other was observed. DST, India and Riber, France are acknowledged.

9481-30, Session PThu

Studies on abrupt and gradual heterostructured hole barriers in barrier enhanced InAs/GaSb superlattice long wavelength photodetectors

Yi Zhou, Jianxin Chen, Fangfang Wang, Zhicheng Xu, Li He, Shanghai Institute of Technical Physics (China)

InAs/GaSb strained type-II superlattices (SLs) are the III-V counterpart to the established HgCdTe (MCT) infrared (IR) detection technology thanks to its theoretic advantages by D. L. Smith et al. However, the issues of unwanted high dark currents and low R0A values still exist for the type II technology, especially for long wavelength detectors. One of the most important features of InAs/GaSb superlattice system is the freedom of band structure tunability. Advanced heterostructure detectors have shown significant dark current reduction over the conventional PIN photodiode.

Our earlier work showed that a PBIN structure with an electron barrier inserted between P type contactor and absorption region significantly improved the electrical performances compared to a PIN structure. The R0A product of the PBIN detector was measured to be 104 Ωcm2 at 80K and 7360 Ωcm2 at 50K.

In this work, studies were first conducted to P-type doped PBϖN structures (where ϖ stands for the doped absorption region). Be-doping was employed to convert the conductivity of the long wavelength SL structure, the PN junction moves away from the B-I hetrostructure to the ϖ-N interface where the materials on sides are long wavelength SL structure. And therefore, it loses the barrier effect and a hole barrier is also needed to form a PBϖBN structure. The long wavelength SL structure was made of periodic 15 monolayers (MLs) InAs and 7 MLs GaSb with 50% cutoff wavelength around 11 ?m. The electron barrier consisting of 7 ML InAs/ 7 ML GaSb and the hole barrier used in our structure consists of 8 ML InAs/ 3.5 ML GaSb. Both of the abrupt and gradual heterojuncton will be studied in our experiments. The gradual band gap structure was designed to inserted between the absorber region and the hole barrier to avoid the peak barrier in the band structure which could block the photo-generated current of the detector. Our initial result demonstrated that the PBϖBN structure with an abrupt heterojunction showed significantly improved electrical performances compared to PBϖN structure and also the high quantum efficiency. The R0A product of the PBϖBN detector was measured to be 17.5 Ωcm2 and the dark current density under -0.05V bias was measured to be 8.8x10-4A/cm2 at 80K. The peak current responsivity at 9.8 μm was 2.15A/W and the quantum efficiency was 26.7%.

Further work will conduct to the comparison of the electric and optic performance of different hole barrier structures with or without Al element.

9481-31, Session PThu

Automated optical system alignment and low order wavefront sensing

Joyce Fang, Dmitry Savransky, Cornell Univ. (United States)

Good optical alignment systems provide us with high precision images, efficient detecting methods, and superior sensing techniques in optical instruments. The benefits of such a system will address three major considerations in optical instrumentation: First, with the myriad reconfigurable systems, each with moving parts, aligning the optical components manually is very time and energy consuming. Second, some satellites and aerospace instruments cannot be serviced after their launch. A slight inaccuracy in the engineering design or disturbance during launch or on orbit might cause optical misalignment. Finally, automated misalignment can greatly aid in the deployment of all kinds of distributed optical systems that require a quick set up. A self-aligning optical system improves the performance of multiple optical instruments. The innovation of this research is that the automated optical alignment systems can self-align and self-heal by using low-order sensing without wavefront sensors. A single lens system with four degrees of freedom is discussed. The goal is to calibrate the shifts of the lens in two directions, and calibrate the tip and tilt of the lens. The laser beam goes through the lens mounted on the stages and outputs a final image on the CCD camera. The final image is then sent to the measurement system where the algorithm is executed to get the measurement result. We use center of mass (COM), principal component analysis (PCA), and Gaussian ellipse fitting for feature detection. Besides the shift of image center, the shape of the image will deform from a circle to an ellipse-like shape when applying tip and tilt misalignments on the lens. We use the aspect ratio of the semi-major and minor axes, together with the rotation of the ellipse, to find the tip-tilt misalignments, and decouple tip-tilt and shift misalignments. Finally, the system feeds back the detected misalignments and the control loop is established. An estimation process is designed to minimize the measurement error. We set up an experiment based on our simulation. We constantly revise the measurement and estimation methods to improve the result. The modeling, simulation, together with the physical experiment, demonstrate the concept of our automated alignment design.

9481-32, Session PThu

Fluorescence of quantum dots on e-beam patterned and DNA origami substrates

Timothy C. Corrigan, Matthew Kessinger, Ina Nikolli, Concord Univ. (United States); Michael L. Norton, David Neff, Marshall Univ. (United States)

Attachment of quantum dots or fluorescent molecules to gold nanoparticles has a variety of optical labeling and sensing applications. In this study, we use both e-beam lithography and DNA origami to examine the fluorescence enhancement of fluorescent molecules and quantum dots with a systematic approach to understanding the contribution of gold nanoparticle size and interparticle spacing. The unique design of our e-beam patterns allows us to study the effects of size and spacing of the gold nanoparticles on the enhancement of fluorescence in single, rapid, parallel on chip studies with constant conditions – removing undesirable effects such as differences in concentration of quantum dots or other chemistry differences that plague multiple experiments. Our use of DNA origami allows us to study sizes and spacings difficult to achieve with lithography. We further discuss the fluorescence and bonding of CdSe/ZnS quantum dots to both gold as well as DNA for use in self-assembled DNA constructs. We will present fluorescent images showing results of optimal size and spacing for fluorescence from the patterned samples as well as AFM images demonstrating attachment chemistry of the quantum dots to the DNA/gold substrates.

9481-33, Session PThu

Analysis for simplified optics coma effection on spectral image inversion of coded aperture spectral imager

Yangyang Liu, Qunbo Lv, Linlin Pei, Jianwei Wang, Academy of Opto-Electronics (China)

As a novel spectrum imaging technology was developed recent years, push-broom coded aperture spectral imaging(PCASI) has the advantages of high throughput, high SNR, high stability etc. This coded aperture spectral imaging utilizes fixed code templates and push-broom mode, which can realize the high-precision reconstruction of spatial and spectral information. But during optical lens designing, manufacturing and debugging, it is inevitably exist some minor coma errors. Even minor coma errors can reduce image quality. In this paper, we simulated the system optical coma error's influence to the quality of reconstructed image, analyzed the variant of the coded aperture in different optical coma effection, then proposed an accurate curve of image quality and optical coma quality in code template, which provide important references for the design and development of push-broom coded aperture spectrometer.

9481-34, Session PThu

Random laser action in al nanoparticle/Rh6G-doped silica gel

Chao Yang, Guoying Feng, Hong Zhang, Jiayu Yi, Jiajia Yin, Shouhuan Zhou, Sichuan Univ. (China)

We report the first observation of random laser action in metal nanoparticle/laser dye-doped bulk material. Al nanoparticles with an average particle size of 100 nm are provided as the scatters and Rh6G doped silica gel as the gain medium. A significant lasing mode centered at 559.7 nm has been observed above the threshold. The intensity of laser emission varies from different directions. The specific output wavelength and remarkable machinability as well as the physical and chemical stability both make it a novel random laser source for potential applications in biosensors.

9481-35, Session PThu

Maximum allowable low-frequency platform vibrations in high resolution satellite missions: challenges and look-up figures

Javad Haghshenas, Satellite Research Institute (Iran, Islamic Republic of)

Performance of high resolution remote sensing payloads is often limited due to satellite platform vibrations. Effects of Linear and high frequency vibrations on the overall MTF are known exactly in closed form but the low frequency vibration effect is a random process and must be considered statistically. It should be considered in system level payload designing to know whether or not the overall MTF is limited by the vibration blur radius. Usually the vibration MTF budget is defined based on the mission requirements and the minimum resolvable contrast. With a good understanding of harmful vibration frequencies and amplitudes in the system preliminary design phase, if the satellite platform vibrations are more severe than the allowed quantity, their effects could be removed totally or partially considering a stabilization mechanism in the system level payload designing procedure. This procedure is cost effective and let designer to just eliminate the harmful vibrations and avoids over-designing.

In this paper we have analyzed the effects of low-frequency platform vibrations on the payload's modulation transfer function. We have used a statistical analysis to find the probability of imaging with a MTF greater or equal to a pre-defined budget for different missions. After some discussions on the worst and average cases, we have proposed some "look-up figures" which would help the remote sensing payload designers to avoid the vibration effects. Using these figures, designer can choose the electro-optical parameters in such a way, that vibration effects be less than its pre-defined budget. Furthermore, using the results, we can propose a damping profile based on which vibration frequencies and amplitudes must be eliminated to stabilize the payload system

9481-36, Session PThu

Choosing the right video interface for military vision systems

John Phillips, Edward Goffin, Pleora Technologies Inc. (Canada)

This presentation will discuss how standards-based video interfaces – the technology used to transfer data from a camera or image sensor to a mission computer or display – can help military imaging designers reduce size, weight, power, cost, and complexity while increasing usability and intelligence.

This presentation will introduce the GigE Vision standard, which regulates video transfer and device control over Ethernet networks. Traditionally, military imaging systems have used interfaces based on analog, Camera Link, or LVDS standards, which limit component choice, increase costs, and result in more complex systems.

In comparison, GigE allows designers to support required point-to-point connections while gaining the flexibility of video networking, the ability to interwork with a range of different computing platforms, and the benefits of light-weight, low-cost cabling. Moreover, these interfaces have been field-hardened in demanding industrial applications.

Using military vetronics as an example, we'll highlight how designers can employ GigE Vision interfaces, including GigE cameras or external frame grabber that convert feeds from existing cameras into more manageable video . We will also discuss new vision technologies for military imaging. This includes GigE over wireless to eliminate cabling complexity, and transcoding technology that compresses GigE Vision video in a widely available format and wirelessly transmits feeds to playback devices, including laptops, tablets, and smartphones, or recording devices.

Hosted by member of Pleora's product management team, designers of vision systems for defense and security applications will leave this presentation with a greater technical understanding on how the video interface can influence the cost, complexity, usability and performance of end-systems.

9481-37, Session PThu

Nanomolecular gas sensor architectures based on functionalized carbon nanotubes for vapor detection

Deon Hines, Henan Zhang, The City College of New York (United States); Mark Ruemmeili, IBS Center for Integrated Nanostructure Physics, Institute for Basic Science (IBS) (Korea, Republic of); David Adbimpe, Polymath Interscience, LLC (United States); Daniel L Akins, The Graduate School of the City University of New York and CASI, The City College of New York (United States)

Specifically, the project involves the development of a diversified array of nanostructured gas-sensors comprised of selectively, novel surface-functionalized carbon nanotubes (for analyte selectivity by virtue of functionality). Harnessing carbon nanotubes with various electron withdrawing and donating groups help in determining their affinity toward certain prognostic gaseous markers thus increasing specificity of such created sensors. We have devised synthetic routes that have led to the facile production of covalently polyfunctionalized nanotubes in high yield. Seven carbon nanotube analogues were systematically considered and then chemically synthesized, from pristine single-walled nanotubes (SWNT's), for use as the main component of sensory units that was used for this study. The ability to manufacture total organic sensors was demonstrated using carbon nanotube based architectures.

These derivatized-nanotube-based materials are designed to serve as chemoreceptors that can facilitate the development of highly selective and sensitive chemical and biological sensor arrays through an "electronic nose" approach which mimics the mammalian olfactory system. Functionalized SWNTs (f-SWNTs) were dispersed in dimethyl formamide (DMF) and mCresol and spun-applied to the interdigitated regions of micro-lithographically fabricated, pre-cleaned interdigitated microsensor electrodes. Measured changes in the electrical conductivities of an array of gas sensors upon exposure to selected vapors and inert explosive materials were monitored. These changes are transduced into electrical signals, which are preprocessed and conditioned before identification by a pattern recognition system. Also, preliminary chemosensory work was conducted on four signature vapor components of RDX explosive. Sensor data from these individual detection methods was assessed by their own individual merits, after which they were amalgamate and reclassified to present each vapor as a unique data point on a 2-dimensional map and with a minimum loss of information. Extensive characterizations on the properties of these materials were carried out using various spectroscopic and electrical techniques to assess the usefulness of functionalized single-walled carbon nanotubes. It was found that the conductivity of two functionalized materials were more conductive than the pristine SWNT.

The development of consistent and successful functionalization techniques that allows for the construction of CNTs-based species of great usefulness, reversibility and selectivity for the use as sensing element, were demonstrated. Further studies into electronic and electrochemical detection methods will provide more unique systems for R&D on the applicability of these materials to future technology.

9481-54, Session PThu

Non-uniformity correction with temperature influence compensation in microbolometer detector

Michal Krupinski, Grzegorz Bieszczad, S?awomir Gogler, Henryk Madura, Military Univ. of Technology (Poland)

Because of a significant impact of the microbolometer array temperature on the infrared image quality, it is necessary to compensate the influence of the temperature on the NUC process. In the most common applications two approaches are used: the first is a stabilization of the microbolometer array temperature by a thermoelectric cooler, the second is updating correction coefficients obtained from reference source, for example a shutter. Both of the most common approaches have theirs disadvantages. The first case needs a considerable amount of energy for temperature stabilisation. The second one needs a reference target and a mechanical procedure to place the target at the front of the detector. Additionally, during calibration the reference target is blocking radiation from the scene, thus interrupting measurements with the thermal camera. In the article a non-uniformity correction method is presented which allows to compensate for the influence of detector's temperature drift. For this purpose, dependency between output signal value and the temperature of the detector array was investigated. Additionally the influence of the temperature on the Offset and Gain coefficients was measured. Presented method utilizes estimated dependency between output signal of detectors and their temperature. In the presented method, the dependency between output signal value and the temperature of the detector is estimated during time of starting detector. The coefficients are estimated for every pixel. In the article proposed method allows to compensate the influence of detectors temperature fluctuation and increase a time between shutter actuation process.

9481-55, Session PThu

High-sensitivity active pixel sensor with variable-threshold photodetector

Sung-Hyun Jo, Myunghan Bae, Byoung-Soo Choi, Kyungpook National Univ. (Korea, Republic of); Hong-Kun Lyu, Daegu-Gyeongbuk Institute of Science and Technology (Korea, Republic of); Jang-Kyoo Shin, Kyungpook National Univ. (Korea, Republic of)

CMOS image sensors (CISs) are increasingly used in low-level light detection systems such as fluorescence imaging, biomedical and chemical experiments. Many photodetector elements are available in CMOS, such as n+/p-well, p+/n-well, and n-well/p-sub junctions for the application of imagers. However, the photodetectors for low light levels require very high responsivity, which is difficult to implement by using CMOS technologies, because the noise and quantum efficiency degrade due to CMOS scaling into nanometer region. The avalanche photodiode (APD) is an alternative device that can simultaneously achieve high responsivity and high speed, when operating as a single-photon counter. However, the avalanche charge multiplication requires higher operational voltages. Higher bias voltages of APDs are not compatible with the peripheral circuits in a standard CMOS technology.

A novel high-sensitivity active pixel sensor (APS) with variable-threshold photodetector using standard CMOS technology has been presented. The proposed APS has a gate/body-tied PMOSFET-type photodetector with an overlapping control gate that makes it possible to control the sensitivity of the proposed APS. It is a hybrid device composed of a metal-oxide-semiconductor field-effect transistor (MOSFET), a lateral bipolar junction transistor (BJT) and a vertical BJT. Using sufficient overlapping control gate bias to operate the MOSFET in the inversion mode, the variable-threshold photodetector allows for increasing the photocurrent gain by 105 at low light intensities. Thus, the proposed APS with variable-threshold photodetector has a better low-light-level sensitivity than the conventional APS, and it has a variable sensitivity which is dependent on the control gate bias. Maximum sensitivity of the proposed APS is 50 V/lux•s. The proposed sensor has been fabricated by using 0.35 ?m 2-poly 4-metal standard complementary MOS (CMOS) process and its characteristics have been evaluated.

Conference 9482: Next-Generation Spectroscopic Technologies VIII

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9482-2, Session 1

A perspective on the development of portable and hand-held Fourier transform infrared (FT-IR) spectrometers and their application *(Invited Paper)*

David W. Schiering, Josep Arnó, Smiths Detection Inc. (United States)

We will discuss the development of portable and hand-held FT-IR spectrometers primarily from the perspective of defense and security applications. The technological and instrumental methods development will be emphasized with selected example applications.

9482-3, Session 1

Chromium speciation using battery-operated microplasmas-on-chips and optical emission spectrometry

Jenisse German, Vassili Karanassios, Univ. of Waterloo (Canada)

Speciation is generally defined as the determination of the concentration of an analyte (such as Chromium) in a given oxidation state. Determination of the concentration of an analyte in the oxidation state that it exists in the environment is important for toxicity reasons. Consider Chromium (Cr) as an example. Although Cr can exist in as many as 11 oxidation states, in the environment only two oxidation states are thermodynamically stable, that is Cr(III) and Cr(VI). In terms of toxicity, Cr(III) is an essential micro-nutrient but Cr(VI) is carcinogenic. For Cr speciation, samples are collected in the field, where they are acidified prior to their shipment in a lab for concentration determinations (typically, by using an Inductively Coupled Plasma (ICP) spectrometer. Acidification may alter the oxidation state. Further changes in the oxidation state can occur due to possible storage prior to analysis. It appears that it would be ideal if Cr-speciation took place on-site. But ICPs are large and heavy and cannot be brought to the field.

For the last several years we have been developing and characterizing battery-operated microplasmas-on-chips. Their intended application is for chemical analysis on-site (i.e., in the field). In this presentation, Cr-speciation will be discussed and preliminary results for Cr-speciation will be presented.

9482-4, Session 1

Review and recent progress of handheld spectrometry at Thermo Fisher Scientific *(Invited Paper)*

Peidong Wang, Thermo Fisher Scientific Inc. (United States)

We will describe the history and background of portable and handheld spectrometry at Thermo Fisher Scientific. The handheld instruments range from elemnetal detections based on enegy-dispersive XRF to molecular identifications using Raman, NIR and FTIR and their combinatory techniques. We will also discuss our recent progresses and their applications.

9482-5, Session 1

A new point of care device for the detection of transcutaneous bilirubin index based on a novel optical probe

Hasan B. Celebi, Yunus Karamavus, Yildiz Uludag, TÜBITAK National Research Institute of Electronics and Cryptology (Turkey)

In neonatal jaundice, excess bilirubin in the blood diffuses into the surrounding tissue causing yellowing of the skin. Diffuse reflectance spectroscopy is a non-invasive spectroscopic technique for studying the optical properties of a biological tissue and hence can be used to detect ihe infants' transcutaneous bilirubin index (TcB) from the skin tissue. Here, a novel point-of-care device is presented for the determination of the TcB that utilizes diffuse reflectance spectroscopy. The proposed device contains an optical plexyglass head that is easier to manufacture, more compact and more affordable than the optical fiber probes. This optical head consists of two nested plexyglass rods. The outer rod is used to expose the skin surface with a white light produced by a LED. And the reflected light emerging from the various layers of the tissue is collected by the inner rod, which is coupled to a spectrometer. The spectral information that is obtained by the scan of the skin is processed with an effective algorithm enabling theaccurate calculation of the TcB.

9482-6, Session 1

A full featured handheld LIBS analyzer with early results for defense and security

David R. Day, Brendan Connors, Morgan Jennings, SciAps, Inc. (United States); John Egan, Konstantin Derman, Paul Soucy, Suzanne Moller, SciAps (United States); Don Sackett, SciAps, Inc. (United States)

A handheld LIBS instrument has been designed that includes most features found in large bench-top systems including variable gating, argon purge, good resolution, sample rastering and video targeting. In this presentation we will discuss the feature selection, trade-off decisions and new developments that made this kind of size reduction possible. Early results will be presented for elemental presence detection and quantification with specific emphasis on defense and security.

9482-7, Session 1

Security and defense applications with a novel handheld mass spectrometer

Christopher D. Brown, 908 Devices Inc. (United States)

We report on development progress and evaluation of a high-pressure handheld mass spectrometer designed for multiphase analysis of safety/security oriented materials such as warfare agents/precursors, toxic industrial chemicals and explosives. Hostile environment testing, ROC analysis and limits of detection will be discussed, along with the engineering challenges associated with operating a highly miniaturized mass spectrometer in such applications.

9482-8, Session 1

Towards a chip-scale integrated-optic TDLAS methane sensor

Michael B. Frish, Matthew C. Laderer, Physical Sciences Inc. (United States)

Natural gas leaks from pipelines are potential safety risks as well as greenhouse gas sources. With increasing emphasis on natural gas as an energy resource, there is concomitant emphasis on improving leak detection using cost-effective methane sensor networks, yet suitable sensors are lacking.

This paper describes progress towards developing miniature methane sensors, based on integrated optics and Tunable Diode Laser Absorption Spectroscopy (TDLAS), intended for low-cost mass production and low power consumption in a cell-phone style package. TDLAS is a configurable, robust, and reliable gas sensing technology. TDLAS methane sensors are insensitive to ambient gases other than methane. While current state-of-the-art compact near-IR TDLAS methane sensors achieve the basic performance and goals for networks (sensitivity ~200 ppm methane, insignificant cross-sensitivity to other vapors, 60 second response to abnormal methane), their cost (exceeding $5,000 per unit) and power demand (~1W) must both diminish by at least an order-of-magnitude to practically serve the envisioned need.

To this end, we have built and demonstrated a simplified TDLAS package having no macro optics or TEC, intended for low-cost mass production and low power consumption. It utilizes a silicon substrate for supporting the laser chip, detector photodiode, and thermal control components. By eliminating the TEC and operating the laser in heated mode, precise temperature stabilization is maintained with a simple resistive heater, reducing system power consumption for thermal control by more than 80%. Bulk optical components are eliminated while maintaining sensor performance suitable for detecting methane at the concentrations of interest.

9482-9, Session 1

Interband cascade laser spectroscopic sources with extremely low power budgets

Jerry R. Meyer, Chul Soo Kim, U.S. Naval Research Lab. (United States); Mijin Kim, Sotera Defense Solutions, Inc. (United States); William W. Bewley, Charles D. Merritt, Chadwick L. Canedy, Igor Vurgaftman, U.S. Naval Research Lab. (United States)

Interband cascade lasers (ICLs) emitting in the midwave infrared have advanced dramatically in recent years, mostly due to improved designs of the active and optical confinement regions of the GaSb-based heterostructures. While the more mature intersubband-based quantum cascade laser (QCL) has received considerable attention as a source for new IR spectroscopy systems, ICLs will be advantageous in most applications requiring < 20 mW of single-mode output power at any wavelength in the range ≈ 3-6 microns. This is because ICLs have lower threshold current densities and also much lower operating voltages than QCLs, making their typical drive powers at least an order of magnitude smaller. Besides extending battery lifetimes, the implication is a substantial reduction of the overall footprint and weight of the source component of fielded spectroscopic sensing systems. With demonstrated drive powers as low as 30 mW, and the potential to reduce that metric by another factor of 3-10, one can envision using solar panels to power unattended ICL-based sensors.

This talk will review the current status of ICL development at NRL. Recent advances include the observation of up to 18% cw wallplug efficiency at 25 °C, cw output powers up to 464 mW with beam quality M2 = 1.9, obtained by corrugating the ridge sidewalls to suppress higher-order transverse modes, and the demonstration of interband cascade LEDs whose maximum cw output power of 1.6 mW at 25 °C is higher than for any previous mid-IR LED. Limits on the minimum practical drive power and maximum wavelength tuning by a single element will be discussed.

9482-11, Session 2

Characterization of ion-assisted induced absorption in A-Si thin-films used for multivariate optical computing

Aditya B. Nayak, Jimmy Price, Bin Dai, David Perkins, Ding Ding Chen, Christopher M. Jones, Halliburton (United States)

Multivariate optical computing (MOC), an optical sensing technique for analog calculation, allows direct and robust measurement of chemical and physical properties of complex fluid samples in downhole environments of high temperature and pressure.

The core of this MOC technology is the integrated computational element (ICE) optical computing element, an optical filter with a transmission spectrum designed to allow the detector to respond sensitively and specifically to the analytes of interest. A key differentiator of this technology is that it uses all of the information present in the broadband optical spectrum to determine the proportion of analytes present in a complex fluid mixture. The detection methodology is photometric in nature; therefore, this technology does not require a spectrometer to collect a spectrum or a computer to perform calculations on the optical spectrum.

The integrated computational element is a thin-film optical element with a specific optical response function designed for each analyte. The optical response function is achieved by fabricating alternating layers of high-index (a-Si) and low-index (SiO_2) thin films onto a transparent substrate using an ion-assisted e-beam vacuum deposition process. A proprietary software and process are used to control the thickness and material properties, including the optical constants of the materials during deposition to achieve the desired optical response function. The ion-assisted deposition is very useful for controlling the densification of the film, stoichiometry, and material optical constants, as well as to achieve high deposition growth rates and moisture-stable films. However, the ion-source can induce undesirable absorption in the film and subsequently modify the optical constants of the material during the ramp-up and stabilization period of the e-gun and ion-source, respectively. This paper characterizes the unwanted absorption in the a-Si thin-film using advanced thin-film metrology methods, including spectroscopic ellipsometry, cross-section scanning electron microscope (SEM) and transmission electron microscope (TEM), and X-ray diffraction (XRD). The resulting analysis identifies a fundamental mechanism contributing to this absorption and a method for minimizing unwanted absorption in the thin-film such that the exact optical response function can be achieved.

9482-12, Session 2

Photoacoustic sensing with micro-tuning forks *(Invited Paper)*

Ulrike Willer, Clausthal University of Technology (Germany); Michael Köhring, Fraunhofer Heinrich Hertz Institute (Germany); Mario Mordmüller, Clausthal University of Technology (Germany); Wolfgang Schade, Fraunhofer Heinrich Hertz Institute (Germany) and Clausthal University of Technology (Germany)

Photoacoustic spectroscopy is an established method for sensitive detection of trace gases. With the invention of QEPAS – quartz-enhanced photoacoustic spectroscopy – at Rice University, photoacoustic spectroscopy gained even more acceptance since this method provides enhanced noise immunity and a high sensitivity due to the use of a quartz micro tuning fork as photoacoustic transducer at its resonance frequency. Addition of acoustic micro-resonators leads to further signal enhancement. Different schemes of their arrangement are now known as on-beam and off-beam QEPAS. Trace detection of important gases for industrial and environmental sensing has been demonstrated with detection limits ranging from ppm to ppt range, depending on pressure, excitation wavelength,

absorption strength, laser power and molecular parameters. Also the surrounding gas mixture, e.g. humidity influences the signal by promoting or delaying de-excitation and vibrational-translational-transfer.

Even though sensitivity depends linearly on exciting power, we could also demonstrate QEPAS using LEDs, setting up cost efficient and small sensing devices.

Using quartz tuning forks, the motion of the prongs is monitored by measuring the piezo current that is induced within quartz as piezoelectric material. This property can also be used to drive the tuning fork into motion by electrical excitation. New sensing schemes relying on the simultaneous or alternate electrical and photoacoustic excitation of the tuning fork will be presented and discussed.

Quartz micro tuninig forks are readily available because of their use within watches. However, their design and the resulting resonant frequency of 32 kHz are not ideal for the detection of slowly relaxing molecules. Using tuning fork structures in other materials provides new possibilities regarding the choice of material parameters and geometry, however at the expense of the ease of using the piezo-electric readout for monitoring the induced motion. Here, interferometric readout can circumvent this drawback and provides new possibilities for the setup of integrated sensors.

QEPAS as sensing technology will be reviewed and new developments regarding further miniaturization, different readout mechanisms and detection schemes will be discussed.

9482-13, Session 2

Latest developments in DLP based NIR spectrometers enable the next generation of compact, portable systems

Eric Pruett, Pedro Gelabert, Texas Instruments Inc. (United States)

Designing the next generation of compact, portable NIR spectrometers while meeting aggressive cost and form factor targets requires novel technologies and creative system designs. New miniature spectrometer architectures are enabled by Texas Instruments DLP® technology. The ability to provide programmable spectral filters using high speed, accurate light modulation with a MEMS based architecture enables systems with features and sampling techniques previously not possible. System design considerations and the latest developments in DLP® based spectrometer architectures will be presented.

9482-14, Session 2

Quantitative energy-dispersive X-ray diffraction for identification of counterfeit medicines: preliminary study

Chiaki Crews, Daniel O'Flynn, Aiden L. Sidebottom, Robert D. Speller, Univ. College London (United Kingdom)

The prevalence of counterfeit and substandard medicines has been growing rapidly over the past decade, and fast, non-destructive techniques for their detection are urgently needed to counter this trend. In this study, energy-dispersive X-ray diffraction (EDXRD) combined with chemometrics was assessed for its effectiveness in quantitative analysis of compressed powder mixtures. Although EDXRD produces lower-resolution diffraction patterns than angular-dispersive X-ray diffraction (ADXRD), it is of interest for this application as it carries the advantage of allowing the analysis of tablets within their packaging, due to the higher energy X-rays used.

A series of caffeine, paracetamol and microcrystalline cellulose mixtures were prepared with compositions between 0 - 100 weight% in 20 weight% steps (22 samples in total, including a centroid mixture), and were pressed into tablets. EDXRD spectra were collected in triplicate, and a principal component analysis (PCA) separated these into their correct positions in the mixture space. A partial least-squares (PLS) regression model calibrated using this training set was validated using a test set of six samples (mixtures in 8:1:1 and 5?:2?:2? ratios), giving a root-mean square error of prediction (RMSEP) of 1.3, 2.2 and 2.1 weight% for caffeine, paracetamol and cellulose respectively. The model also showed some capability to predict amounts of paracetamol and/or caffeine in over-the-counter medicines, even though constituents not included in the calibration were present.

These initial results are promising, with RMSEP values on a par with those reported in the ADXRD literature. The impacts of this work will be discussed.

9482-15, Session 2

Long-wave infrared spectroscopy for trace chemical agent detection using hypersorbent materials

Dmitry A. Kozak, R. Andrew McGill, Todd H. Stievater, Viet Nguyen, Robert Furstenberg, Marcel W. Pruessner, U.S. Naval Research Lab. (United States)

We report long-wave infrared (LWIR, 5-15 micron) differential absorption spectra of several chemical warfare agent simulants reversibly sorbed to an NRL hypersorbent coating. A sorbent coated zinc-selenide crystal served as the evanescent surface for attenuated total reflectance Fourier transform spectroscopy (ATR-FTIR) . In this work a custom hydrogen-bond (HB) acidic carbosilane polymer 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.

The LWIR is a promising region for trace gas detection due to the presence of numerous strong individual vibrational absorption resonances. While the absorption spectra for most vapor-phase chemicals in that spectral region are well-known, their rapid detection and identification at trace concentrations in short optical interaction lengths in ambient air is challenging, especially in the presence of mixtures or other interfering chemicals. Sorbent materials specifically designed to preferentially sorb and concentrate analytes of interest, such as nerve agents, allow detection at a parts-per-billion level.

The measured LWIR differential absorption spectra show complex changes in the resonances for the sorbent material itself, as well as new resonances arising from chemical bonding between the analyte and the sorbent. Both of these sets of spectral features combined together form a unique signature for analyte identification. We also report the dependence of the signal strength on the analyte concentration, and show how the sensitivity correlates with the gas-sorbent partition coefficient for that analyte.

9482-16, Session 2

Developing mobile LIBS solutions for real world applications

Qun Li, Katherine A. Bakeev, Jing Li, Sean X. Wang, B&W Tek, Inc. (United States)

We present a new type of handheld Laser-Induced Breakdown Spectroscopy (LIBS) spectrometer for developing mobile atomic spectroscopy solutions for real world applications. A micro diode-pumped passive Q-switched solid-state laser with high repetition rate of well above 1kHz in comparison to 1-10Hz as used in a traditional LIBS instrument is employed to produce a train of laser pulses. The focused laser spot is further fast scanned over a pre-defined area, hence generating several hundreds of micro-plasmas per second at different locations. Synchronized miniature CCD array spectrometer modules collect the LIBS signal and generate LIBS spectra. By adjusting the integration time of the spectrometer to cover a plurality of periods of the laser pulse train, the spectrometer integrates the LIBS signal produced by a plurality of laser pulses. Hence the intensity of the obtained LIBS spectrum can be greatly improved to increase the signal-to-noise ratio (SNR). This unique feature of the high repetition rate laser based LIBS

system allows it to measure elements at trace levels (ppms) , hence reducing the limit of detection (LOD). The increased signal intensity also lessens the sensitivity requirement for the optical spectrometer. In addition, the energy of the individual laser pulse can be reduced in comparison to traditional LIBS system to obtain the same signal level, making the laser pulse is less invasive to the sample. The typical measurement time is within 1-2 seconds. Several examples of real world applications will be presented.

9482-17, Session 2

Spectral analysis of rare earth elements

Madhavi Z. Martin, Oak Ridge National Lab. (United States); Andrzej W. Miziolek, U.S. Army Research Lab. (United States); Robert V. Fox, Idaho National Lab. (United States); Frank C. DeLucia Jr., U.S. Army Research Lab. (United States); Nicolas André, University of Tennessee (United States)

There is growing interest in rapid analysis of rare earth elements (REEs) both due to the need to find new natural sources to satisfy increased demand in their use in various electronic devices, as well as the fact that they are used to estimate actinide masses for nuclear safeguards and nonproliferation. Laser-Induced Breakdown Spectroscopy (LIBS) appears to be a particularly well-suited spectroscopy-based technology to rapidly and accurately analyze the REEs in various matrices at low concentration levels (parts-per-million). Although LIBS spectra of REEs have been reported for a number of years, further work is still necessary in order to be able to quantify the concentrations of various REEs in real-world complex samples. LIBS offers advantages over conventional solution-based radiochemistry in terms of cost, analytical turnaround, waste generation, personnel dose, and contamination risk. Rare earth elements of commercial interest that are divided into the following three groups have been reported, 1) raw ores and unrefined materials, 2) refined products such as magnets, lighting phosphors, consumer electronics (which are mostly magnets and phosphors), catalysts, batteries, etc., and 3) waste/recyclable materials (aka e-waste). LIBS spectra for REEs such as Dy, Eu, Gd, La, Nd, Sm, and Y will be presented.

9482-19, Session 3

Is "good enough" good enough for portable visible and near-visible spectrometry? *(Invited Paper)*

Alexander Scheeline, SpectroClick (United States)

Some uses of portable spectrometers require the same quality as laboratory instruments. Such quality is challenging because of temperature and humidity variation, dust, and vibration. Typically, one chooses materials and mechanical layout to minimize the influence of these noise and background sources. Mechanical stability is constrained by limits on instrument mass and ergonomics. An alternative approach is to make minimally adequate hardware, compensating for variability in software. We describe an instrument developed specifically to use massive software to compensate for marginal hardware. An initial instantiation of the instrument is limited to 430 – 700 nm. Simple changes will allow expansion to cover 315 – 1000 nm. Outside these ranges, costs are likely to increase significantly.

Inherent wavelength calibration comes from knowing the peak emission wavelength of an LED light source, and fitting of instrument dispersion to a model of order placement with each measurement. Dynamic range is determined by the product of camera response and intentionally wide variation in throughput among hundreds of diffraction orders. Resolution degrades gracefully at low light levels, but is limited to ~ 5 nm at high light levels as initially fabricated and ~ 1 nm in principle. High stray light is measured in real-time. Diffuse stray light can be employed for turbidimetry or to indicate fluorescence acting as a source of working curve nonlinearity. While unsuitable for, e.g, Raman spectroscopy, the instrument shows promise for absorption, fluorescence, reflectance, and surface plasmon resonance. To satisfy the needs of non-expert users, real-time training, measurement sequencing, and outcome interpretation are programmed with QR codes or web-linked instructions. Limitations to doing everything on cell phones and means to overcome those limits are described.

9482-20, Session 3

Demonstration of G-Fresnel cellphone spectrometer

Chenji Zhang, The Pennsylvania State Univ. (United States); Perry S. Edwards, Atoptix, LLC. (United States); Zhiwen Liu, The Pennsylvania State Univ. (United States)

Cellphone has attracted a lot of active interest as a portable platform for compact and economical design of conventional laboratory instruments. Here, we present a high-performance cellphone spectrometer using a novel hybrid dispersion device, 'G-Fresnel', which features dual functions of focusing and dispersion. We fabricated G-Fresnel using soft lithography and designed a prototype cellphone spectrometer by place it in front of a cellphone camera. Due to G-Fresnel based device's dual functions, the spectrometer can achieve high performance despite its compact form factor. The light coming through a slit at a predetermined angle is collimated, dispersed and focused onto the CMOS sensor inside the cellphone camera. In order to compensate for the response of the Bayer filter inherent in the color detector, an inversion algorithm is developed to retrieve the target spectrum from the image recorded on the cellphone camera. Furthermore, spectral holography method is used to characterize the device resolution. The spectrometer is shown to achieve nm resolution across the visible range. As proof of concept demonstration of our designed spectrometer, we measured fluorescence spectrum of dyed micro-sphere and achieved good comparison with that measured with a commercial spectrometer.

9482-21, Session 3

Smartphone spectroscopy: three unique modalities for point-of-care testing *(Invited Paper)*

Kenneth D. Long, Hojeong Yu, Brian T. Cunningham, Univ. of Illinois at Urbana-Champaign (United States)

We demonstrate three principle modalities for a smartphone-based spectrometer: absorption, fluorescence, and photonic crystal (PC)-based label-free detection. When combined with a few simple optical components, the rear-facing CMOS cameras in a mobile device can provide spectrometric data that rivals that of laboratory instruments, but at a fraction of the cost. The use of a smartphone-based platform poses significant advantages based upon the rise of smartphone apps, which allow for user-interface and data-processing algorithms to be packaged and distributed within environments that are externally maintained with significant potential for useful integration with services such as cloud storage, GIS-tagging, and remote expert analysis.

First, we will compare a smartphone-based spectrometer with a conventional 96-well plate reader for the quantification of enzyme-linked immunosobent assays (ELISA), a mainstay of immunological testing. Limits of detection using the smartphone-based instrument were found to be identical to those obtained with a laboratory instrument for a common cancer biomarker (human IL-6) in bovine serum and peanut allergen (ara h1) in commercially available cookies. These analytes demonstrate the broad applicability of such a handheld sensor that could be used in both clinical and consumer-based settings. Secondly, we will compare a smartphone-based spectrometer with a traditional fluorimeter for performing a molecular beacon (MB) assay for a specific RNA sequence. Fluorescent based assays, such as MB, are well-suited to point-of-care applications as they provide single-step analysis of samples without additional labeling and washing steps. Using a representative miRNA implicated in cardiovascular

disease and certain cancer morphologies (miR-21) we demonstrate a limit of detection of 1.3 pM, representing a value lower than that obtained using a laboratory instrument. In addition, we were able to successfully quantify single-base mutations in the target sequence. The ability rapidly quantify target DNA from samples presents a promising tool for the development of point-of-care tools to detect biological and chemical species including bacteria, viruses, and environmental pathogens. Finally, we will demonstrate PC-based detection of a representative label-free assay using the interaction between Protein A and human immunoglobulin G (IgG) in the nanomolar concentration regime. By measuring the shift in peak wavelength value (PWV) from an increase in effective refractive index due to biomolecular adsorption onto the PC surface, a direct quantification of target analyte can be achieved without any labeling molecules. This sensing modality is particularly amenable to point-of-care testing, as it eliminates labeling reagents from assay protocols, something especially important with biological labels that must be refrigerated.

Our work represents the first demonstration of smartphone-based spectroscopy for performing biological assays, and the first mobile-device-enabled detection instrument that serves to measure three distinct sensing modalities (label-free biosensing, absorption spectroscopy, and fluorescence spectroscopy). The smartphone platform has the potential to expand the use of spectrometric analysis to environments assay from the laboratory, which may include rural or remote locations, low-resource settings, and consumer markets.

9482-22, Session 3

iSPEX: a smartphone spectropolarimeter

Frans Snik, Stephanie Heikamp, Ritse C. Heinsbroek, Felix C. M. Bettonvil, Gerard van Harten, Christoph U. Keller, Leiden Observatory (Netherlands); Jeroen H. H. Rietjens, SRON Netherlands Institute for Space Research (Netherlands); Ramón Navarro, NOVA Optical Infrared Instrumentation Group (Netherlands); Arnoud Apituley, Koninklijk Nederlands Meteorologisch Instituut (Netherlands); Hester Volten, Rijksinstituut voor Volksgezondheid en Milieu (Netherlands); Armand Perduijn, Bright LED Solutions BV (Netherlands); Sipke Wadman, Willem Hoving, Avantes B.V. (Netherlands); Norbert Schmidt, DDQ (Netherlands)

We developed the iSPEX optical add-on for the iPhone (types 4, 4S, 5 and 5S), which turns the built-in camera into a spectropolarimetric sensor. The spectrometer optics consist of an entrance slit, a plastic collimator lens and a plastic transmission grating. The linear polarization is measured by plastic retarders and a polaroid sheet, which imprint the degree and the angle of linear polarization as the amplitude and phase of a sinusoidal modulation on the intensity spectrum. Snapshots with the smartphone camera thereby instantaneously record both spectral and polarization information. We have manufactured thousands of iSPEX units, distributed them to citizen scientists across the Netherlands, and produced unique maps of atmospheric aerosols based on iSPEX measurements of the cloud-free sky. We describe the optomechanical design of the iSPEX unit, the data handling by the iSPEX app and the data reduction of submitted iSPEX measurements. Furthermore, we discuss the opportunities for iSPEX to perform quantitative spectroscopy with a smartphone camera.

9482-23, Session 3

Quantum dots, CMOS sensors and cell phones toward point-of-care-diagnostics *(Invited Paper)*

Eleonora Petryayeva, W. Russ Algar, The Univ. of British Columbia (Canada)

The unique optical properties of semiconductor quantum dots (QDs) have attracted considerable interest for assay and biosensor development. This presentation will describe our recent efforts to utilize mass-produced consumer electronic components, such as LEDs and CMOS image sensors, in combination with QDs, to develop point-of-care assay methods and technologies. The high brightness, broad absorption spectra, and narrow emission from QDs are ideally suited to these applications, and excel where conventional fluorescent dyes cannot. To illustrate, we will first present ratiometric Foerster resonance energy transfer (FRET)-based assays of proteolytic enzyme activity on paper test strips, as well as triply multiplexed homogeneous assays of proteolytic activity in bulk solution. These assays use low-power, inexpensive light sources and either digital cameras, webcams, or smartphone cameras for readout. In each case, the RGB color filters and corresponding image pixel values provide a measure of fluorescence from the system, which is coupled to enzymatic activity through energy transfer. We will then show how QDs, FRET, LEDs, and CMOS sensors can be used for assays on blood samples, highlighting the design considerations that are important for such a point-of-care device, along with the benefits and liabilities of the overall strategy. Finally, we conclude with recent results toward paper-based analytical devices that use smartphone readout for the ratiometric detection of proteins. Overall, the optical properties of QDs are very promising for developing point-of-care assays, particularly when combined with readout methods based on consumer electronics and mobile devices.

9482-24, Session 3

Mobile phone based mini-spectrometer for rapid screening of skin cancer

Anshuman J. Das, Tristan B. Swedish, Akshat Wahi, Mira Moufarrej, Marie Noland, Thomas Gurry, Edgar Aranda-Michel, Deniz Aksel, Sneha Wagh, Vijay Sadashivaiah, Xu Zhang, Ramesh Raskar, Massachusetts Institute of Technology (United States)

We demonstrate a highly sensitive mobile phone based spectrometer that has potential to detect cancerous skin lesions in a rapid, non-invasive manner. Earlier reports of low cost spectrometers utilize the camera of the mobile phone to image the field after moving through a diffraction grating. These approaches are inherently limited by the closed nature of mobile phone image sensors and built in optical elements. The system presented uses a novel integrated grating and sensor that is compact, accurate and calibrated. Resolutions of about 10 nm can be achieved. Additionally, UV and visible LED excitation sources are built into the device. Data collection and analysis is simplified using the built in audio/video interfaces and logical control on the smart phone. Furthermore, by utilizing an external sensor, the mobile phone camera can be used in conjunction with spectral measurements. We are exploring ways to use this device to measure endogenous fluorescence of skin in order to distinguish cancerous from non-cancerous lesions with a mobile phone based dermatoscope.

9482-25, Session 3

Portable computing for mobile micro-instruments: from hand held devices to smart phones and tablets in spectroscopy

Scott Weagant, Vassili Karanassios, Univ. of Waterloo (Canada)

There is an undeniable trend toward miniaturization of analytical instrumentation. In many respects, spectroscopic instrumentation is leading this trend. Currently, all analytical instruments (including those that are lab-based) include a computer. In the past, lap top computers appeared to be a viable option for portable instrumentation. Other options also existed. Included among them were palm-size computing-devices. Recently, smart phones and tablets are offering new opportunities for computing and for

control of chemical analysis portable-instrumentation that can be used on-site (i.e., in the field). In this presentation, portable-computing for use in conjunction with chemical analysis instrumentation that can be used in the field will be described in detail. Example will be drawn for the literature and from the author's laboratory.

9482-26, Session 3

Smartphone-embedded chemical luminescence-based biosensors for point-of-need applications

Aldo Roda, Elisa Michelini, Luca Cevenini, Donato Calabria, Maria M. Calabretta, Martina Zangheri, Massimo Di Fusco, Massimo Guardigli, Mara Mirasoli, Patrizia Simoni, Univ. degli Studi di Bologna (Italy)

We present smartphone-embedded portable biosensors for the detection of clinically relevant analytes through biospecific reactions. The analysis relied on the imaging and quantification of the light emitted by different luminescence processes, e.g., chemiluminescence (CL), bioluminescence (BL) and thermochemiluminescence (TCL), by the smartphone-embedded camera. Disposable analytical cartridges and accessories for the implementation of the biosensors have been designed and fabricated using low-cost 3D printing technology, thus enabling rapid prototyping. Back-illuminated complementary metal-oxide semiconductors (BI-CMOS) cameras integrated into smartphones showed suitable for the luminescence detection and e phone apps were used to enable long exposure times (20-30s) to achieve the needed detectability and for data handling.

As a proof-of-principle we report enzymatic and immuno-assays for cholesterol, bile acids, lactate and cortisol relying either on BL (bacterial luciferase) or CL (luminol-H2O2-horseradish peroxidase system) reactions and employing different analytical formats (such as microfluidic cartridges and lateral-flow immunoassay). These assays can be performed within short times (i.e., few minutes) in a very straightforward manner and provided adequate quantitative analytical performance for the analysis of the target molecules in different matrices (serum, oral fluid and sweat). We also investigated the use of TCL by synthesizing TCL labels for bioprobes based on novel 1,2-dioxetane derivatives and designing a miniaturized, battery-powered heater to implement TCL detection in the smartphone-embedded biosensor.

Smartphone-based chemical luminescence detection could be thus applied to a variety of clinical chemistry assays and other analytes useful for any point-of-need applications including critical medicine, bioterrorism, developing country and space medicine.

9482-27, Session 3

Gas detection with microelectromechanical Fabry-Perot interferometer technology in cell phone

Rami Mannila, Risto Hyypiö, Anna Rissanen, VTT Technical Research Ctr. of Finland (Finland); Marko Korkalainen, VTT Technical Research Ctr of Finland (Finland); Martti Blomberg, Hannu Kattelus, VTT Memsfab (Finland)

This paper presents optical sensing technology with potential to miniaturize and integrate carbon dioxide (CO2) into small mobile instruments such as cell phones. Our miniaturized gas sensors are based on a microelectromechanical (MEMS) Fabry-Perot interferometer (FPI), which is a tunable optical filter structure, where two highly reflective mirror surfaces are separated by an electrically actuated air gap. The MEMS FPI is a monolithic device, i.e. it is made entirely on one substrate in a batch process, without assembling separate pieces together. MEMS massmanufacturing in large volumes brings down the cost of individual chip elements, enabling novel applications for gas sensing technology for mobile sensors and novel IOT (Internet of Things) applications.

VTT's optical MEMS (MOEMS) Fabry-Perot interferometers were first developed in the 1990s with the realization of Vaisala's Carbocap ® carbon dioxide gas sensor, which operates in the mid-infrared (MIR) wavelength range. Development of the MEMS process integration technology has enabled the customisation of filter structures in terms of optical specifications based on different application requirements. In this presented demonstrator, a FPI operating in wavelength range where CO2 has strong absorption (3.5-4.5 μm), is integrated to shield cover of the cell phone. This sensor consists of a light source, gas cell, MEMS-FPI, detector and Bluetooth connection to cell phone. The use of a FPI structure enables realisation of a compact, low-cost, stable mid-infrared (MIR) microspectrometers for sensors as a single-beam, multi-wavelength approach that allows measurement of multiple spectral points with only one detector and a single light source. The benefits of such a setup compared to several separate detectors include very good long-term stability and high selectivity and similar approach can be used also other gas detection. VTT has earlier develop MEMS-FPI platform also for hydrocarbon detection in the wavelength range 3-3.7 μm. Absorptions of the hydrocarbons are not as strong as carbon dioxide's, but with a novel optical structure it is possible to realize long path length in small footprint. Therefore this technology can enable the detection of also other gases, such as hydrocarbons, in cell phone.

9482-28, Session 4

MEMS for imaging spectrometry from the visible to the long wave infrared wavelengths

Dilusha K. K. M. B. D. Silva, Dhirendra K. Tripathi, Haifeng Mao, John Bumgarner, Mariusz Martyniuk, Jarek Antoszewski, John M. Dell, Lorenzo Faraone, The Univ. of Western Australia (Australia)

Much work has been done in the past on MEMS based spectrometers for various applications. The difficulties in using MEMS based spectrometers for imaging applications relates to difficulties in obtaining MEMS structures large enough to cover all or a significant part of a focal plane array. Particulary with surface micromachining, optical tuneable filters are generally limited in size to the order of 100 micron in lateral dimension. Our recent work has focused on achieving two objectives. Firstly, expanding the lateral size of our tuneable filter devices to the millimetre scale to allow them to cover all or a significant portion of a focal plane array. Secondly, expanding the operational wavelength range beyond the shortwave infrared, where a lot of our work had focussed on in the past. We have worked towards the implementation of filters at shorter wavelengths, down into part of the visible spectrum, as well as longer wavelengths, into the longwave infrared band. Our latest results demonstrate tuneable filters with novel designs operating over most of the longwave infrared, as well as partial results towards the implementation of high-quality tuneable filters in the midwave infrared, shortwave infrared, and into part of the visible spectrum. The devices demonstrated are significantly larger in size compared to our traditional devices, with dimensions ranging up to 2mm x 2mm or bigger.

9482-29, Session 4

Determination of stress in silicon wafers using Raman spectroscopy

Martin De Biasio, Lukas Neumaier, Natalie Vollert, Carinthian Tech Research AG (Austria); Eduard Geier, Michael Rösner, Infineon Technologies Austria AG (Austria); Christina Hirschl, Martin Kraft, Carinthian Tech Research AG (Austria)

Currently, manufacturing of integrated semiconductors sees a strong

trend towards the use of thin silicon substrates, e.g. for top-efficiency power devices. However, with the reduction of substrate thickness inherent mechanical stresses may cause warpages, which poses manufacturing and handling challenges. These stress states are known to be strongly affected by the process history of a wafer, rendering a careful optimisation and alignment of the process steps and parameters vital for high-yield zero-defect production. One major problem in this is the lack of suitable metrology devices capable of reliable and rapid stress mapping and quantification.

The Raman-active Si phonon peak at 520.5 cm-1 responds to inherent stresses by a 2 cm-1/GPa shift of its centre wavelength; this effect has been used variously for local stress mapping, e.g. in MEMS devices or of strongly doped active sites. Here, the possibility of using Raman microspectrometry as a metrology tool for spatially resolved quantification of absolute stress levels on entire production-scale wafers was researched. Combining Raman measurements of silicon samples expose to calibrated stress loads with analytically calculated stress levels, it could be shown that the necessary analytical accuracy can be achieved. Involving actual wafers taken from a qualified manufacturing process it could subsequently be shown that it is indeed possible to reliably measure mechanical stress in entire silicon wafers and relate these results e.g. to different thinning process parameters. The method thus proved its potential as a valuable tool for semiconductor manufacturing process optimisation and quality control, at-line or eventually even in-line.

9482-30, Session 4

Fuel flexibility via real-time Raman fuel-gas analysis for turbine-system control

Michael P. Buric, Benjamin T. Chorpening, Steven D. Woodruff, David Tucker, National Energy Technology Lab. (United States)

The modern energy production base in the U.S. is increasingly incorporating opportunity fuels like biogas, coalbed methane, coal syngas, solar-derived hydrogen, and others. In many cases, suppliers operate turbine-based generation systems to efficiently utilize these diverse fuels. Unfortunately, turbine engines are difficult to control given the varying energy content of these fuels, combined with the need for a backup natural gas supply to provide continuous operation. Here, we study the use of a specially designed Raman Gas Analyzer based on capillary waveguide technology with sub-second response time for turbine control applications. The NETL Raman Gas Analyzer utilizes a low-power visible pump laser, and a capillary waveguide gas-cell to integrate large spontaneous Raman signals, and fast gas-transfer piping to facilitate quick measurements of fuel-gas components. A U.S. Department of Energy Turbine facility known as HYPER (hybrid performance system) serves as a platform for a-priori fuel composition measurements for turbine speed or power control. A fuel-dilution system is used to simulate a compositional upset while simultaneously measuring the resultant fuel composition and turbine response functions in real-time. The feasibility and efficacy of system control using the spontaneous Raman-based measurement system is then explored with the goal of illustrating the ability to control a turbine system using available fuel composition as an input process variable.

9482-32, Session 4

Modular reconfigurable matched spectral filter spectrometer

Elizabeth C. Schundler, James R. Engel, OPTRA, Inc. (United States); Thomas C. Gruber Jr., MESH, Inc. (United States); Robert Vaillancourt, Ryan Benedict-Gill, David J. Mansur, John Dixon, Kevin Potter, OPTRA, Inc. (United States)

OPTRA is currently developing a modular, reconfigurable matched spectral filter (RMSF) spectrometer for the monitoring of greenhouse gases. The heart of this spectrometer will be the RMSF core, which is a dispersive spectrometer that images the sample spectrum from 3 – 5 micron onto a digital micro-mirror device (DMD) such that different columns correspond to different wavebands. By applying masks to this DMD, a matched spectral filter can be applied in hardware. The core can then be paired with different fore-optics or detector modules to achieve active in situ or passive remote detection of the chemicals of interest. This results in a highly flexible system that can address a wide variety of chemicals by updating the DMD masks and a wide variety of applications by swapping out fore-optic and detector modules. In either configuration, the signal on the detector is effectively a dot-product between the applied mask and the sample spectrum that can be used to make detection and quantification determinations. Using this approach streamlines the data stream produced by the sensor without reducing the information content, therefore making it ideal for remotely or unattended systems. This paper will focus on the design and anticipated performance of the RMSF core.

9482-33, Session 5

High spatial resolution LWIR hyperspectral sensor

Carson B. Roberts, Andrew Bodkin, James T. Daly, Bodkin Design & Engineering, LLC (United States)

The Air Force has need of a Long Wave Infrared (LWIR) Hyperspectral imager with simultaneously high spectral and spatial resolution. Most hyperspectral imaging systems sacrifice spatial resolution for spectral resolution. As a result, the imagery that contains spectral information which may be important in target selection will not have the spatial resolution to allow simultaneous detection of objects by shape-based algorithms or human-in the-loop exploitation

Bodkin Design & Engineering (BD&E) has developed hardware and software for the creation of high-resolution hyperspectral images by using a scanning fore-optic, an array of apertures and a dispersive optical processor. The prototype system can generate hyperspectral long wave infrared images at the resolution of the system focal plane array. High resolution images have been created in the Short Wave Infrared (SWIR), and in the LWIR.

The sensor used for these experiments was a modified version of BD&E's LWIR-62 HyperPixel Array™ imager, with a spectral resolution of 62 bands covering the region of 7 to 10.5 μm. The full hyperspectral image was built up from a series of images taken as the fore-optic was scanned by a computer across the scene being imaged. A new set of computer algorithms for spectral calibration and hyperspectral image formation, which intrinsically correct for distortions in the optical system was developed as part of these experiments

In this paper, we will present a description of the scanning fore-optic hyperspectral imaging system, an outline of the algorithms used for spectral calibration, and to multiplex the individual images, as well as laboratory test results and progress-to-date including high resolution hyperspectral images in the LWIR and SWIR.

9482-34, Session 5

Dewar-cooler-integrated MWIR spectrometer for high rates and high-dynamic range measurements

Nicolas Guérineau, Sylvain Rommeluère, Yann Ferrec, Guillaume Druart, ONERA (France); Serge Magli, SOFRADIR (France); Gilles Lasfargues, Commissariat à l'Énergie Atomique (France); Eric D. de Borniol, MINATEC (France)

There is a need for compact, hand-held, spectrometers for the measurement of spectral signatures of chemicals or objects. To achieve this goal, a concept of static Fourier-transform spectrometer directly integrated in the infrared focal plane array has been developed at ONERA. This component is called Microspoc (MicroSpectrometer On Chip). The fundamental properties of this key element will be recalled and we will see how those properties can be exploited to get a compact, cryogenic and snapshot MWIR spectrometer.

These design rules have been applied to develop a very compact device that combines the metrological properties of a FTIR-FPA of quantum HgCdTe technology with the operational performances of a last generation Sofradir detection block (Infrared Detector Dewar Cooler Assembly – IDDCA). The physical dimensions of the prototype are closed to a standard IR camera, that make it well-suited for field measurements.

The experimental performances of the device will be presented, in terms of spectral resolution (typically 75 nm at 5 μm), acquisition rate (up to 500 Hz), field of view (0.6° with a precise circular definition), dynamic range and noise equivalent spectral radiance.

At the end, we will discuss the potential of this technology to meet the requirements of different scenarii of measurements, in the field or on airborne plateforms.

9482-35, Session 5

Compact high performance hyperspectral system design and applications

Leah Ziph-Schatzberg, Corning Incorporated (United States)

Hyperspectral imaging is a fast maturing technology. Applications such as precision agriculture, process monitoring, surveillance, and bio-medical are being investigated around the world. More application-specific algorithms are being developed, and more real-world systems are moving from the research lab to actual use in the field.

Corning Incorporated has been developing and building hyperspectral optical engines, gratings, and slits for over a decade. Corning currently has the capabilities to manufacture precision diamond turned gratings on a variety of materials, practically any shape surface, and wide wavelength ranges. The experience and knowledge developed at Corning during this time have allowed for unique spectrometer designs. Our vertically integrated expert manufacturing facility allows us to build these hyperspectral (HSI) systems. These compact, high performance, lower cost systems are offered at wavelength ranges from the visible to the Long Wave Infrared (LWIR). The low Size Weight and Power (SWAP) of these HSI systems enables applications that are not possible with other systems, such as installations on small unmanned aerial vehicles (UAVs), and mobile short range applications. Mobile applications are also enabled by Corning's built-in scanner that works seamlessly with the push-broom imaging spectrometer and Corning's proprietary software to collect data cubes with a small, tripod mounted integrated device.

We discuss the proprietary design of Corning's HSI systems, as well as our manufacturing capabilities that are necessary to make these systems cost-effectively in quantities. In this paper we discuss the specific designs of Corning HSI vis-NIR, SWIR and uncooled LWIR systems and their performance. We also discuss the use of these systems for real-world applications.

9482-36, Session 5

Portable stand-off spectral imaging camera for detection of effluents and residues

Neil Goldstein, Benjamin St. Peter, Jonathan Grot, Michael Kogan, Marsha Fox, Pajo Vujkovic-Cvijin, Ryan Penny, Jason A. Cline, Spectral Sciences, Inc. (United States)

A new, compact and portable camera, employing a MEMs-based spectral imaging approach, has been built and demonstrated for detection of hazardous contaminants including gaseous effluents and residues on surfaces. The camera is called the Thermal infrared Reconfigurable Analysis Camera for Effluents and Residues (TRACER). TRACER operates in the long wave infrared and has the potential to detect a wide variety of materials with characteristic spectral signatures in that region. The 30 lb. camera is tripod mounted and battery powered. A touch screen control panel provides a simple user interface for most operations. The MEMS component is a Texas Instruments Digital Microarray Device (DMD) with custom electronics and firmware control. Simultaneous 1D-spatial and 1D-spectral dimensions are collected, with the second spatial dimension obtained by scanning the internal spectrometer slit. The sensor can be configured to collect data in several modes including full hyperspectral imagery using Hadamard multiplexing, wide-band thermal imagery, and contrast imagery from any analog filter, all with a simple User command. Matched filters can be generated internally on-the-fly and applied in hardware, substantially reducing detection time and improving SNR over HSI software processing, while reducing storage requirements. Results of preliminary field trials on representative effluent and surface residue materials will be presented.

9482-37, Session 5

Detection and direct identification of liquid contaminants at standoff distances with an imaging polarimetric spectrometer

Eugene Tsiang, Spectrum Photonics, Inc. (United States)

Imaging Fourier transform spectrometry has been used for the remote detection and identification of liquid surface contaminants, including biospills and hazardous chemicals. The measured spectra and their polarization depend on the optical properties of the liquid, as described by the complex refractive index. A common practice is to measure the imaginary part of the refractive index and to calculate the real part from Kramers-Kronig relations, or vice versa. Another common practice is to rely on a library of refractive index of materials for matching model and experimental spectra. Instead, we propose a method for extracting the complex refractive index directly from the differential polarization spectra, using an adaptation of a technique used in semiconductor ellipsometry. The sensor employed for validating the method is the Sagnac interferometer, a LWIR spatial interferometer (8 - 12 micron) for hyperspectral imaging adapted for emission and reflection polarimetry by the incorporation of linear analyzers between the scene and the camera.

A field demonstration was conducted using linear polarizers as analyzers in the instrumental Mueller matrix chain. The liquid implemented in our testing was SF96, an inert silicon oil commonly used as a surrogate for toxic chemicals. The sensor was positioned at various angles of incidence to the liquid and substrate. Linear polarizers were set at fixed angles of 0, 45 and 90 degrees with respect to the incoming plane of polarization. There was no retarder plate, such as a quarter wave plate, inserted between the sample and the detector. The directional anisotropic emissivities and hemispherical reflectance distribution functions for the liquid and substrates were measured. Complex refractive index was obtained by inverting the Fresnel specular reflectance model.

Given the absence of a retarder plate in the setup, our optical train does not directly account for circularly polarized illumination. In this approach the possibility of circular polarization is left as a free parameter, to be determined after computation of n and k values. The Mueller matrix elements for Fresnel reflection from a liquid on a substrate can be determined from the directional emissivity matrix. These can then be used to determine the contribution of the cold sky to specular reflection, which was found to require only a small correction. Results with the SF96 liquid experiment showed good agreement of the complex refractive index with published values, especially as the direction of incoming illumination approached Brewster's angle. The results indicate that the approximate thicknesses of the liquid layer can be determined as well.

Significant improvement in signal-to-clutter ratio may be achieved using an imaging polarimetric approach when compared to conventional methods. In this work we have focused on remote sensing of liquids, but the approach also applies to any surface which has an "effective" refractive index, such as soils that exhibit a general bidirectional reflectance distribution function (BRDF).

9482-38, Session 5

Longwave infrared compressive hyperspectral imager

Julia Rentz Dupuis, Bogdan R. Cosofret, Physical Sciences Inc. (United States); Michael J. Kirby, Colorado State Univ. (United States)

Physical Sciences Inc (PSI) is developing a longwave infrared (LWIR) compressive sensing hyperspectral imager (CS-HSI) based on a single pixel architecture for standoff detection of process plumes indicative of nuclear or radiological material production. The solution employs novel use of a high throughput stationary interferometer and a digital micromirror device (DMD) converted for LWIR operation in place of the traditional cooled LWIR focal plane array. The CS-HSI represents a substantial cost reduction over the state of the art in LWIR HSI instruments. Radiometric improvements for using the DMD in the LWIR spectral range have been identified and implemented. In addition, CS measurement and sparsity bases specifically tailored to the CS-HSI instrument and chemical plume imaging have been developed and validated using LWIR hyperspectral image streams of chemical plumes. These bases enable comparable statistics to detection based on uncompressed data.

In this paper, we present a system model predicting the overall performance of the CS-HSI system. Results from a breadboard build and test validating the system model are reported. In addition, the measurement and sparsity basis work demonstrating the plume detection on compressed hyperspectral images is presented.

9482-39, Session 5

Hyperspectral grating optimization and manufacturing considerations

Lovell E. Comstock, Jeffry J. Santman, Corning Specialty Materials, Inc. (United States)

Hyperspectral imaging systems are finding broader applications in both the commercial and aerospace markets. It is becoming clear that to optimize the performance of these systems, their instrument transfer function needs to be tailored for each application. Vis-SWIR systems in the full 400nm to 2500nm waveband present particular design and manufacturing challenges. A single blazed grating is inadequate for a system operating in the full vis-SWIR wavelength range. In addition, optical materials and broad band coatings present a challenge for non-reflective systems. An understanding of the application and wavelengths of interest, combined with a judicious choice of a focal plane array, can then lead to an optimized system for the specific application. The ability to tailor the grating and manufacture a wide variety of grating profiles and substrate shapes becomes a significant performance enabler. This paper will discuss how the use of optical, coating, and grating design/analysis software, combined with grating manufacturing techniques assure meeting high performance requirements for different applications.

9482-10, Session PTue

Micro-Raman spectroscopy for meat type detection

Martin De Biasio, Philip Stampfer, Raimund Leitner, Carinthian Tech Research AG (Austria); Christian Wolfgang Huck, Verena Wiedemair, Institute of Analytical Chemistry and Radiochemistry (Austria); Dirk Balthasar, TOMRA Sorting GmbH (Germany)

Raman spectroscopy can be applied to almost any bio-molecule. If a sample is lit with monochromatic laser light, most of the light is elastically scattered (Rayleigh scattering) with no change in photon energy (or frequency). However, a small portion of the scattered light is inelastically scattered (Raman scattering) with a corresponding shift in frequency. This fraction of the reflected light provides information about the vibrations of molecules. The difference between the incident and scattered frequencies is due to an excitation of the molecular system. A Raman spectrum is obtained by measuring the intensity of the scattered photons as a function of the shift in frequency. These characteristic Raman peaks allow the spectroscopic separation of different molecules or identical molecules in different crystalline forms. Here, we demonstrate the feasibility of using micro-Raman measurements to discriminate chicken, pork, veal, turkey, mutton, beef, horse and lamb. Test sets of meat samples were bought at a number of supermarkets and Raman spectra of the samples measured using the Raman microscope. Characteristic spectral features were identified and used to build a chemometric model. Our experimental results show that it is indeed possible to detect and discriminate different meat types using a Raman system. However as the samples show little differences in their chemical make-up sophisticated data analysis is needed.

9482-54, Session PTue

Divalent chromium doped ZnSe nanoparticles random laser induced by nanosecond laser pulse

Jiayu Yi, Guoying Feng, Chao Yang, Shouhuan Zhou, Sichuan Univ. (China)

Divalent chromium ion doped ZnSe nanocrystalline particles (Cr^{2+}:ZnSe NPs) by nanosecond pulsed laser ablation of polycrystalline Cr^{2+}:ZnSe micron-sized powder in water environment are presented. The SEM and XRD results reveal that the products are ZnSe cubic sphalerite structured with an average size of 20-50 nm. Typical random laser emissions of Cr^{2+}:ZnSe nanoparticles centering at 2180 nm with a threshold of 0.4 mJ/pulse were observed. As the pump energy increasing (above the threshold value), the decay time of the central wavelength reduces to 30 ns from 1.2 ?s. We found that the decay time of the random laser continuously varies with the spectral wavelengthes for the first time. This random laser device may become a more sensitive, selective, smaller and cheaper middle infrared light source.

9482-40, Session 6

Fluorescent marker-based and marker-free discrimination between healthy and cancerous human tissues using hyper-spectral imaging

Thomas Arnold, Martin De Biasio, Raimund Leitner, Carinthian Tech Research AG (Austria)

Two problems are addressed in this paper (i) the fluorescent marker-based and the (ii) label-free discrimination between healthy and cancerous human tissues. For both applications the performance of hyper-spectral methods are quantified. Fluorescent marker-based tissue classification uses a number of fluorescent markers to dye specific parts of a human cell. The challenge is that the emission spectra of the fluorescent dyes overlap considerably. They are, furthermore disturbed by the inherent auto-fluorescence of human tissue. This results in ambiguities and decreased image contrast causing difficulties for the treatment decision. The higher spectral resolution introduced by tunable-filter-based spectral imaging in combination with spectral unmixing techniques results in an improvement of the image contrast and therefore more reliable information for the physician to choose the treatment decision. Marker-free tissue classification is based solely on the subtle spectral features of human tissue without the use of artificial markers. The challenge in this case is that the spectral differences between healthy and cancerous tissues are subtle and embedded in intra- and inter-patient variations of these features. The contributions of

this paper are (i) the evaluation of hyper-spectral imaging in combination with spectral unmixing techniques for fluorescence marker-based tissue classification, (ii) the evaluation of spectral imaging for label-free intra surgery tissue classification. Within this paper, we consider real hyper-spectral fluorescence and endoscopy data sets to emphasize the practical capability of the proposed methods. It is shown that the combination of spectral imaging with multivariate statistical methods can improve the sensitivity and specificity of the detection and the staging of cancerous tissues compared to standard procedures.

9482-42, Session 6

Spectral data analysis approaches for improved provenance classification

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In the last 10 years various chemometric methods have been developed and used for the analysis of spectra generated by Laser Induced Breakdown Spectroscopy (LIBS). One of the more successful and proven methods is Partial Least Squares Discriminant Analysis (PLS-DA). Recently PLS-DA was utilized for purposes of provenance of spent brass cartridges and achieved correct classification at around 93% with a false alarm rate of around 5%. The LIBS spectra from the cartridge samples are rich in emission lines from numerous mostly metallic elements comprising the brass and the cited results were based on the analysis of the full broadband high resolution spectra. It was observed that some of the lines were clearly saturated in all spectra, while others were sometimes saturated due to pulse-to-pulse variation. The pulse-to-pulse variation was also evident in the intensity variations of the spectra within cartridges and between cartridges. In order to improve on the accuracy of the classification we have developed some pre-processing strategies including the removal of spectral wavelength ranges susceptible to saturation and normalization techniques to diminish the effects of intensity variations in the spectra. The results of these efforts aimed at improving performance will be presented.

9482-43, Session 6

Filter selection criteria for the discrimination of strongly overlapping chemical spectra

Kevin J. Major, Menelaos K. Poutous, Kevin F. Dunnill, The Univ. of North Carolina at Charlotte (United States); Kenneth J. Ewing, Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States); Ishwar D. Aggarwal, The Univ. of North Carolina at Charlotte (United States)

Increasing the selectivity of sensors, while at the same time reducing their complexity, size and cost, are challenges to the sensing community. To this end, an area of exploration has been the development of filter-based chemical sensors. We have recently introduced an approach that utilizes multiple, broadband, infrared (IR) filters to enable discrimination of target chemicals, in the presence of potential interferents that have IR spectral signatures in a limited waveband. Our analysis technique, comparative discrimination spectral detection (CDSD), utilizes a set of broad IR transmission filters, to discriminate between a specific target chemical and multiple interferents with strongly overlapping IR spectra. We have demonstrated the ability of this technique to correctly distinguish between chemicals in the carbon – hydrogen stretch region of the IR absorption spectrum (2700 – 3300 cm-1; 3.0 – 3.7 μm).

We present a numerical study exploring the choices of desired filter sets, and the resulting overall discrimination by these filter sets. Filter parameter choices, such as the peak transmission position and bandwidth, are fundamental in filter-based chemical sensing discrimination systems. In this paper, we describe a systematic numerical approach used to explore how filter properties and filter overlap affect corresponding discrimination results. We describe the interaction between the overlapping spectra and various filter sets on both target and interferent chemicals. We discuss which filter parameters provide optimum selectivity for specific target chemicals and how this information can be utilized to select filters for future direct-filter sensors based on this methodology.

9482-44, Session 7

Compact hyperspectral image sensor based on a novel hyperspectral encoder

Alex Hegyi, Joerg Martini, PARC, a Xerox Co. (United States)

A novel hyperspectral imaging sensor is demonstrated that can enable breakthrough applications of hyperspectral imaging in domains that were not previously accessible. Our technology consists of a planar hyperspectral encoder combined with a traditional monochrome image sensor. The encoder adds negligibly to the sensor's overall size, weight, power requirement, and cost (SWaP-C); therefore, the new imager can be incorporated wherever image sensors are currently used, such as in cell phones and other consumer electronics. In analogy to Fourier spectroscopy, the technique maintains a high optical throughput because narrow-band spectral filters are unnecessary. Unlike conventional Fourier techniques that rely on Michelson interferometry, our hyperspectral encoder is robust to vibration and amenable to planar integration. The device can be viewed within a computational optics paradigm: the hardware is uncomplicated and serves to increase the information content of the acquired data, and the complexity of the system, that is, the decoding of the spectral information, is shifted to computation. Consequently, system tradeoffs, for example, between spectral resolution and imaging speed or spatial resolution, are selectable in software. Our prototype demonstration of the hyperspectral imager is based on a commercially-available silicon CCD. The prototype encoder was inserted within the camera's ~1 cu. in. housing. The prototype can image about 35 independent spectral bands distributed from 350 nm to 950 nm, but the technology is extendable over a wavelength range from ~200 nm to ~6 microns, with suitable choice of detector.

9482-46, Session 7

Characterization of AOTF based Spectropolarimetric Imagers from 400 to 1700 nm

Neelam Gupta, U.S. Army Research Lab. (United States); John C. Morgan, U.S. Army Engineer Research and Development Ctr. (United States); Dennis Suhre, DRS Scientific Inc. (United States)

Two prototype hyperspectral imagers that collect hyperspectral and full linear polarization signatures in the visible-near infrared (VNIR) and shortwave infrared (SWIR) regions are developed. Each of these imagers uses a noncollinear acousto-optic tunable filter (AOTF). The spectral region of operation for the first imager is from 450 to 800 nm and the second one from 1000 to 1600 nm. We will present imaging results for these imagers.

9482-47, Session 7

Low SWaP multispectral sensors using dichroic filter arrays

Todd Jennings, John D. Dougherty, Pixelteq, Inc. (United States)

The benefits of multispectral imaging are well established in a variety of applications including remote sensing, authentication, satellite & aerial surveillance, machine vision, biomedical, and other scientific and industrial uses. However, many of the potential solutions require more compact, robust, and cost-effective cameras to realize these benefits. The next generation of multispectral sensors and cameras needs to deliver improvements in size, weight, power, portability, and spectral band customization to support widespread deployment for a variety of purpose-built aerial, unmanned, and scientific applications. 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 image processing, individual spectral channels are de-mosaiced with each channel providing an image of the field of view. This approach can be implemented across a variety of wavelength ranges and on a variety of detector types including linear, area, silicon, and InGaAs. This dichroic filter array approach can also reduce payloads and increase range for unmanned systems, with the capability to support both handheld and autonomous systems. Recent examples and results of 4-9 band dichroic filter arrays in multispectral cameras are discussed. 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 scalable production.

9482-48, Session 8

Inverse analysis of triarylamine-dye transmission spectra

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Inverse analysis of transmission spectra for triarylamine dye in acetone is presented. This analysis employs a parametric model of transmission through a sample of finite thickness, where the permittivity function is represented parametrically by a linear combination of Lorentz oscillator models. The results of this analysis provide estimates of the permittivity function for triarylamine dye, which can be adopted as input data to other types of models, such as those for prediction of transmission and reflectivity spectra for composites containing mixtures of dyes and other materials. In addition, the results of this analysis should contribute to a data base of estimated permittivity functions for practical analysis of spectra.

9482-49, Session 8

Weighted Chebyshev distance classification method for hyperspectral imaging

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The major topic involving pixel labeling in a hyperspectral data cube is classification. In supervised classification, measured hyperspectral testing data is compared with the reference reflectance spectra (spectral signature) of each class to determine whether the input scene contains similar spectral characteristics of specified classes. If a priori information about classes does not exist, unsupervised classification usually in the form of a clustering method is utilized to determine regions which have similar spectral characteristics [1-2].

Among a number of distance measures [3-5], there are two widely used computationally simple deterministic metrics for identification of spectral similarity between unknown spectra and desired spectra. They are the Euclidian Distance (ED) measure and the Spectral Angle Map (SAM) measure. In [6], a spectral similarity method employing Multi Scale - Vector Tunnel (MS-VT) for supervised classification of the materials in hyperspectral imagery was introduced. With this algorithm, a simple spectral similarity based decision rule using reference data was formed. The prediction of multi-level upper and lower spectral boundaries of spectral signatures for all classes across spectral bands constituted the basic principle of the method. The decision criterion for classification of an input vector was based on choosing its class corresponding to the narrowest VT that the input vector fitted in to.

In this study, MS-VT method is improved and a spectral similarity based technique referred to as Weighted Chebyshev Distance (WCD) method for the supervised classification of hyperspectral imagery (HSI) is introduced. Classification procedures can be carried out with VT parameters obtained from specifications of class references. In the case of supervised learning with training data having labeled training vectors, this is also shown to be equivalent to the use of the WCD in which the weights are chosen as an inverse power of the standard deviation per spectral band [7]. The WCD measure used in the method had the ability of not only tracing the total changes of illumination level, but also detecting the shape of the spectral signature. The use of WCD measures in terms of the inverse power of feature standard deviations and optimization of power parameter constitute the most important side of the study.

The paper consists of four sections. In Section 2, the WCD algorithm is introduced. Section 3 discusses experimental results and performance evaluation. Section 4 is conclusions.

In summary, there are three steps of the proposed WCD algorithm as follows:

Step 1: The mean and standard deviation vectors of the classes are calculated by using the training set.

Step 2: The WCD measure of the test pixels are calculated for all classes by using mean and standard deviation vectors.

Step 3: Each test pixel is labeled to a class based on the minimum WCD measure.

The proposed method is tested on AVIRIS Indiana's Pine [8], Botswana and Kennedy Space Center (KSC) [9] data. The algorithms are trained with the same kinds of training sets, and their performances are calculated for the power of the standard deviation. During these studies, various levels of the power parameters are evaluated based on the efficiency of the algorithms for choosing the best values of the weights. Quantitative classification results for AVIRIS, Botswana and KSC data will be given in the full paper.

9482-50, Session 8

Optical system design of a Dyson imaging spectrometer based on Fery prism

Linlin Pei, Academy of Opto-Electronics (China)

Rich feature information can be obtained through the imaging spectrometer. This kind of technology has a wide range of development. Now we focus on the high spectral resolution and its miniaturization. In this paper, we design a kind of Dyson imaging spectrometer based on Fery prism. Its average spectral resolution is 3nm. Its total length is just 225mm.The Fery prism is an modified optical element based on the conventional dispersion prism. The spherical centers of the front and rear surfaces are not on the optical axis, so the light beam will be dispersive through the optical element. Its raius of surfaces can provide a certain focal length. The Fery prism does not need to be placed in the parallel optical path to simplify the collimating lens and the imaging lens in the prism dispersive spectrometer system. We can get a compact imaging spectrometer. Full spectral transmittance of the Fery prism is up to 94%. Compared to the convex grating, it is great improved. The free spectral range of the Fery prism is wider, and the dispersion does not have higher order spectral aliasing problems. This simple spectrometer include only two elements. Its spectral range is from 400nm to 1000nm, covering the near-ultraviolet to near-infrared spectral. The aberrations of each typical spectral are corrected. The imaging spectrometer is excellent performance.

9482-51, Session 8

errors in imaging of computational imaging spectrometer caused by sampling

Jianwei Wang, Academy of Opto-Electronics (China)

An analysis is given of the errors in computational imaging spectrometer that are caused by the sensor sampling the spectrum-mixed images. It shows that if the mask's transparent slit which has the same size as the pixel stretch across two pixels, the reconstructed image consists stripes which relates to the objects. A sampling model, which is based on data acquisition process, is given to describe the phenomenon, and analyze the influence of sampling errors to image reconstruction. The model says that the sampling errors mix part of nearby-objects' s information to the main objects'. The ratio of main objects' information and nearby-objects' information is fixed and needed to be calibrated. At last, a method is proposed to reduce the stripes and its performance is outstanding. In the method, the images are reconstructed, and the ratio increase from 0.01 to 0.5 in a loop statement, and an image evaluation index is introduced simutaneously, then we can get the best result with unconspicuous stripes and the relevant ratio. The result shows that the stripes in the constructed image

9482-53, Session 8

Turbine jet exhaust as proxy for detection of wake vortices

Taumi Daniels, NASA Langley Research Ctr (United States)

This paper describes an analysis of the potential of an airborne hyperspectral imaging IR instrument to infer wake vortices location via turbine jet exhaust as a proxy. The research goal was to determine the requirements for an imaging spectrometer or radiometer to effectively detect the exhaust plume, and by inference, the location of the wake vortices. The effort examines the gas spectroscopy of the various major constituents of turbine jet exhaust and their contributions to the modeled detectable radiance. Initially, a theoretical analysis of wake vortex proxy detection by thermal radiation was realized in a series of simulations. The first stage used the SLAB plume model to simulate turbine jet exhaust plume characteristics, including exhaust gas transport dynamics and concentrations. The second stage used these plume characteristics as input to the Line By Line Radiative Transfer Model (LBLRTM) to simulate responses from an imaging IR hyperspectral spectrometer or radiometer. These numerical simulations generated thermal imagery that was compared with previously reported wake vortex temperature image data. This research is a continuation of an effort to specify the requirements for an imaging IR instrument to make wake vortex measurements. Results of the two-??stage simulation will be reported, including instrument specifications for wake vortex thermal detection. These results will be compared with previously reported results for IR imaging spectrometer performance.

9482-45, Session 9

NASA Goddard's LiDAR, Hyperspectral, and Thermal airborne imager (G-LiHT)

Lawrence A. Corp, Bruce D. Cook, Elizabeth M. Middleton, NASA Goddard Space Flight Ctr. (United States)

Scientists in the Biospheric Sciences Laboratory at NASA's Goddard Space Flight Center (G) have undertaken a unique instrument fusion effort for an airborne package that integrates commercial off the shelf LiDAR, Hyperspectral, and Thermal components. G-LiHT is a compact, lightweight and portable system that can be used on a wide range of airborne platforms to support a number of NASA Earth Science research projects and space-based missions. G-LiHT permits simultaneous and complementary measurements of surface reflectance, vegetation structure, and temperature, which provide an analytical framework for the development of new algorithms for mapping plant species composition, plant functional types, biodiversity, biomass and carbon stocks, and plant growth. G-LiHT and its supporting database are designed to give scientists access to the data that are needed to understand the relationship between ecosystem form and function and to stimulate the advancement of synergistic algorithms. This system will enhance our ability to design new missions and produce data products related to biodiversity and climate change. G-LiHT has been operational since 2011 and has been used to collect data for NASA & USFS sponsored studies, including NASA's Carbon Monitoring System (CMS) and the American ICESat/GLAS Assessment of Carbon (AMIGA-Carb). These acquisitions target a broad diversity of forest communities and ecoregions across the CONUS and Mexico. Here, we will discuss the components of G-LiHT, their calibration and performance characteristics, operational implementation, and data processing workflows. We will also provide examples of higher level data products that are currently under development.

9482-52, Session 9

Drill Core Imaging Spectral Data Catalog System

Taixia Wu, Lifu Zhang, Hongming Zhang, Qingxi Tong, Institute of Remote Sensing and Digital Earth (China)

Drill core provides direct evidence for geological prospecting. Drill core record compiling has been a vital link in geological exploration. We developed a core drill imaging spectrometer record compiling system, which can be used for the core component detection. The core drill Imaging Spectrometer record compiling System include optical system, mechanical structure, data acquisition module, and record compiling software. The optical system was composed of a VNIR imaging spectrometer and a SWIR imaging spectrometer. The two imaging spectrometers measure drill core radiation in the 400–2500 nm wavelength range with spectral resolution of better than 5 nm at VNIR and 10 nm at SWIR. The 0.2 mm spatial resolution and 400-2500 nm spectral range provides abundant information about many important earth-surface minerals. The mine drill core scan experiment result show the system have achieved relative high performance levels in terms of signal to noise ratio and image quality. The system can automatic achieve core spectral data, easy to manage, rapid analysis of the spectral characteristics of core minerals. At the same time, it can be used for permanent preservation drill cores data, for the latter mineral, oil, gas and other geological resource identifier and extraction.

9482-55, Session 9

Shadow removal from VNIR hyperspectral remote sensing imagery with endmember signature analysis

Fatih Omruuzun, Didem Ozisik Baskurt, Middle East Technical Univ. (Turkey); Hazan Daglayan, Atilim University (Turkey); Yasemin Yardimci Cetin, Middle East Technical Univ. (Turkey)

Shadow is one of the major problems encountered in airborne remote sensing applications. In general, trees, terrain slope and man-made objects including electric poles and buildings may cause shadowing in the scene to be investigated. The effect and size of shadow may change with respect to the angle of incident light at data acquisition time. Shadowed areas may inhibit the accuracy of classification, identification and target detection algorithms in visible and near infrared band hyperspectral imagery. This study aims to develop an effective regional shadow removal algorithm using rich spectral information existing in hyperspectral imagery. The proposed method benefits from assuming spectral similarity of shadowed region pixels with neighboring pixels located around shadowed area. Although the shadowed area has lower reflectance values due to inadequacy of incident light, it is expected that this area contains similar spectral characteristics with surrounding shadow- less area. Using this assumption, the endmembers in both shadowed and shadow-less area are extracted by Vertex Component Analysis (VCA). On the other hand, HySime algorithm overcomes estimating number of end-members, which is one of the challenging parts in hyperspectral unmixing. Therefore, two sets of end-members are extracted independently for both shadowed and shadow-less area. The proposed study aims at revealing the relation between these two end-member sets by comparing their pairwise similarities. Finally, reflectance values of shadowed pixels are re-calculated separately for each spectral band of hyperspectral image using this information. Thus, the shadow effect is removed from the shadowed pixels in hyperspectral image. The proposed method was tested on images acquired by Headwall A-Series Visible + NIR hyperspectral sensor during a flight on October 22, 2014 over agricultural areas near Ankara city center.

9482-57, Session 9

Hyperspectral imaging of foods for commercial application

Seung-Chul Yoon, Kurt C. Lawrence, Bosoon Park, Agricultural Research Service (United States)

Hyperspectral imaging is a technology that has been used all the way from space down to bacterial detection. In addition to imaging from far (thousands of kilometers) to near (microscopic), with pixels covering tens of meters down to even nanometers, with spectral ranges from the ultraviolet to the infrared, hyperspectral imaging is being tested and implemented in numerous commercial applications. It is venturing out of laboratory and finding applications in food processing applications. This talk demonstrates the use of hyperspectral imaging of food products in real time. A high-speed hyperspectral imaging system, including hyperspectral camera system, robust computer, enclosure, lighting, and universal software, was developed and demonstrated for use in detecting diseased chicken carcasses or chicken carcasses containing fecal contamination. The real-time imaging system is able to operate at commercial line speeds of up to 200 birds per minute. The same high-speed hyperspectral imaging system, using different wavelengths and algorithms, can be easily modified via software alone to detect either condition. In other research, a hyperspectral imaging system was also able to detect foreign materials in dried fruit. The system images the fruit on a conveyor at belt speeds of about 0.5 m/s (30 m/min). The hyperspectral system has been interfaced with a robot and is capable of rapidly removing foreign material. Thus, researchers have been able to demonstrate rapid prototyping and commercial potential of this versatile imaging platform.

9482-58, Session 9

Miniaturization of high-spectral-spatial-resolution hyperspectral imagers on unmanned aerial systems

Sam 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, the Nano-Hyperspec®, which provides full hyperspectral resolution and traditional hyperspectral capabilities without sacrificing performance to accommodate the decreasing SWAP of smaller and smaller UAS platforms. The analysis will examine the Nano-Hyperspec flown in several UAS airborne environments and the correlation of the systems data with LiDAR and other GIS datasets.

Conference 9483: Terahertz Physics, Devices, and Systems IX: Advanced Applications in Industry and Defense

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9483-1, Session 1

Terahertz isolator in asymmetry magneto-metasurface *(Invited Paper)*

Sai Chen, Fei Fan, Pengfei Wu, Nankai Univ. (China); Bo Liu, Shengjiang Chang, Key Lab. of Optical Information Science and Technology (China)

In this work, we have investigated the nonreciprocal transmission of a terahertz (THz) isolator based on the magneto-metasurface. A structured InSb layer coats on the silica substrate in which the numerical simulation shows that this metasurface has isolation over 60dB at 0.646 THz and a 10dB operating bandwidth of 13 GHz under an external magnetic field of 0.3T with an insertion loss less than 2.5dB. Importantly, we have discussed the necessary conditions to form THz nonreciprocal transmission in the magneto-metasurface, which closely depends on the magneto-optical material and the relations of the structure asymmetry, wave polarization direction and external magnetic field direction. Moreover, the isolation dependences and tunability of this device on the external magnetic field have also been investigated, which shows the best operating state with a high isolation can be well designed for the device. This kind of low-loss, high isolation, easy coupling THz magneto-metasurface isolator has broadly potentials for THz application systems.

9483-2, Session 1

Enhancement of THz signal intensity by plasmonic monopole nanoantenna *(Invited Paper)*

Ekmel Özbay, Bilkent Univ. (Turkey)

We have designed, fabricated and measured localized surface plasmon resonance (LSPR) based monopole nano-antenna coupled photo-conductive antennas (PCAs) for THz-time domain spectroscopy (TDS) systems. LT-GaAs material was used to fabricate the THz PCAs. The performance of the nano-antenna coupled PCAs was compared to the standard PCAs. The THz signal level has increased by a factor of 2 by using the plasmonic monopole nanoantenna.

9483-4, Session 1

Study on gas molecule adsorption-desorption dynamics on graphene using terahertz emission spectroscopy *(Invited Paper)*

Iwao Kawayama, Osaka Univ. (Japan); Saikat Talapatra, Southern Illinois Univ.-Carbondale (United States); Robert Vajtai, Pulickel Madhavapanicker Ajayan, Junichiro Kono, Rice Univ. (United States); Tonouchi Masayoshi, Osaka Univ. (Japan)

The attractive physical properties of graphene make it suitable for nanomaterial-based devices. But being an atomically thin system means its inherent properties highly susceptible to the physically adsorbed gas molecules. This makes it crucial to study gas adsorption-desorption dynamics in graphene. Raman spectroscopy is one of the most useful tools for characterizing basic properties of graphene samples, including the defect density, the degree of strain, and the number of layers. However, it does not provide direct information on the effect of molecular adsorbates, and their spatial distribution, on the conductivity.

In this study we demonstrate a new approach to visualize the distribution of molecular adsorbates on graphene using terahertz emission spectroscopy and imaging. We found that the waveforms of terahertz radiation from graphene-coated InP sensitively changed with the type of the atmospheric gas, the laser illumination time. The terahertz waveform change is explained through band structure modifications in the InP surface depletion layer due to the presence of localized electric dipoles induced by adsorbed oxygen. These results demonstrate that terahertz emission serves as a local probe for monitoring adsorption and desorption processes on graphene, suggesting a novel two-dimensional sensor for detecting local chemical reactions. We will also present the characteristics of THz emission from graphene/semiconductor substrate under various conditions.

9483-39, Session 1

GaN-based terahertz quantum cascade lasers *(Invited Paper)*

Wataru Terashima, Hideki Hirayama, RIKEN (Japan)

Quantum cascade lasers (QCLs) that utilize optical inter-subband transitions (ISBTs) in superlattices are promising and practical terahertz (THz) laser sources, because they have advantageous characteristics such as compact, continuous-wave operation, narrow line-width, high-power, high-efficiency, maintenance-free, and low-cost. III-nitride semiconductors having huge longitudinal optical phonon energies are promising as materials to solve a problem of "development of operational frequency range (5-12 THz)" on THz-QCLs. In this study, for the purpose of THz lasing from target subband levels, we designed and fabricated unique quantum cascade (QC) structures whose active regions consisted of 2QWs per one period and the number of wave-functions contributed to lasing is limited to minimum 3 subband levels. (i.e., Pure 3-level laser system).

We fabricated THz-QCLs, whose dimensions were ~1.5 mm and 120 ?m for a resonant length and a ridge width, respectively, with QC structures of pure 3-level laser system (100-200 periods) through a radio-frequency molecular beam epitaxy (RF-MBE) and a metal organic chemical vapor deposition (MOCVD) on MOCVD-growth AlGaN/AlN templates grown on c-plane sapphire substrates. Clear satellite peaks in XRD analyses could be observed, indicating that layer structures were stacked with a good periodicity. By comparing data with simulation spectra, it was found that error of film thicknesses were 1-3 %.

We observed sharp lasing spectra with peaks at frequencies of 5.47 THz and 6.97 THz whose full width at half maximum (FWHM) values were close to those of resolution of FTIR spectrometer, when we tried pulse current injection measurements into THz-QCL devices. We successfully for the first time realized GaN-based THz-QCL devices lasing at almost the same frequencies as the target ones by designing a 2QWs-type QC structure with a pure 3-level laser system. We also successfully achieved lasing at ~5.5 and ~7.0 THz, which are highest reported to date for any kinds of THz-QCLs.

9483-5, Session 2

Terahertz metamaterials for modulation and detection *(Invited Paper)*

Sameer Sonkusale, Pramod Singh, Saroj Rout, Guoqing Fu, Wangren Xu, Tufts Univ. (United States)

This talk will illustrate some new concepts in the area of hybrid metamaterials, metamaterials that are embedded with active circuit elements such as transistors. Such transistor/metamaterial hybrids can exhibit some exotic electromagnetic properties which can be exploited for unusual and exciting functions. Two specific examples are provided. In one application, terahertz (THz) modulator based on embedding of psuedomorphic high electron mobility transistor (pHEMT) within the metamaterial resonator, all implemented monolithically in a commercial gallium arsenide (GaAs) technology is presented. In another application, a detector array based on metamaterial perfect absorber for room-temperature detection of gigahertz (GHz) radiation within each sub wavelength metamaterial unit cell is presented. The latter application utilizes a hybridization of metamaterial on printed circuit board (PCB) with discrete microwave electronic components. This concept can be easily scaled to terahertz spectrum through monolithic implementation in CMOS or GaAs processes. Both applications indicate the promise of the approach of integrating electronics or semiconductor devices with metamaterials for new and innovative functions for terahertz spectrum.

9483-6, Session 2

Terahertz-wave detector modules implementing zero-biased InGaAsP Schottky-barrier diodes *(Invited Paper)*

Hiroshi Ito, Kitasato Univ. (Japan)

The Schottky-barrier diode (SBD) is a practical THz-wave detector that operates at room temperature. For zero-biased operation, use of a material with a low Schottky barrier height is preferable. In this regard, an InP-based material system is one of the best choices. In this paper, two types of InGaAsP SBD modules are presented. The first is a J-band (WR-3) rectangular-waveguide-input SBD module. A resonant matching circuit was integrated with an SBD to improve the sensitivity at around the resonant frequency. It showed a sensitivity peak at around 350 GHz with a 3-dB bandwidth of about 80 GHz. The peak sensitivity was 1460 V/W at 350 GHz. To our knowledge, this is the highest value ever reported for a zero-biased InP-based SBD at around this frequency. The second is a quasi-optical SBD module for broadband operation with linear polarization characteristics. An SBD was integrated with a modified bowtie antenna and assembled in a quasi-optical module with a Si hyper-hemispherical lens. We could detect signals at frequencies from 30 GHz to 1 THz. A typical sensitivity obtained was 1080 V/W at 250 GHz. We also confirmed that the polarization angle was stable with a degree of polarization larger than 95 % at frequencies from 80 to 600 GHz. These results indicate that the fabricated quasi-optical SBD module is suitable for sub-THz-wave measurements that require polarization sensitivity without using an external polarizer.

9483-7, Session 2

THz-wave parametric amplifier using LiNbO3 crystal *(Invited Paper)*

Kodo Kawase, Nagoya Univ. (Japan) and RIKEN (Japan); Kosuke Murate, Kazuki Imayama, Nagoya Univ. (Japan); Shin'ichiro Hayashi, RIKEN (Japan)

The emission of high-power THz radiation has received much recent research attention. Various methods, including optical rectification of femtosecond pulses in non-linear inorganic and organic crystals, such as lithium niobate (LiNbO3) have been reported to generate high-power THz radiation. These methods can produce THz EM waves with peak electric fields of a few MV/cm. In addition, injection-seeded THz parametric generation (is-TPG) with a peak power of a few tens of kW has recently been reported by us. These sources have been applied in wide range of fields including THz spectroscopic imaging of illicit drugs hidden in envelopes. Despite the improved performance, it remains difficult to obtain THz spectra and transmission-based images of samples with a large absorption coefficient. To overcome these problems, it is necessary to either increase the power of the THz wave or to improve the sensitivity of the THz detector. One approach to overcoming these limitations is to amplify the THz wave that has been transmitted through the sample. This allows us to easily detect the transmitted THz wave using a conventional room-temperature operated THz sensor, such as a pyroelectric detector.

Based on the fundamental principle of is-TPG, we have demonstrated the amplification of THz wave via parametric processes in a non-linear crystal with a gain of more than 50 dB at room temperature. The non-linear crystals used for the purposes of emission and amplification of the THz waves were pumped separately using a pulsed microchip Nd:YAG laser, which lead to an enhancement of the parametric gain. The energy of both the input and output waves were measured using a calibrated pyroelectric detector (Gentec Inc.) and ND filters for THz-wave. Typically, when the energy of the input THz-wave was approximately 2 fJ/pulse, the output THz-wave was almost 1nJ/pulse.

9483-8, Session 2

Terahertz oscillators and receivers using electron devices for high-capacity wireless communication *(Invited Paper)*

Safumi Suzuki, Masahiro Asada, Tokyo Institute of Technology (Japan)

Recent progress in our room-temperature resonant-tunneling-diode (RTD) terahertz (THz) oscillators and HEMT THz receivers are reported. Oscillations up to 1.55 THz were obtained using a short antenna and an AlAs/InGaAs double barrier RTD with thin-well structure and optimized collector thickness. Using a coherent power combining in a coupled two-element array with offset slot antennas, high output power of 0.6 mW at 620 GHz was obtained. THz communications up to 3 Gbps using RTD oscillator as a transmitter were demonstrated. The data rate was limited by the cut-off frequency of the oscillator, which was determined by the external circuit around the RTD. A structure for high-speed direct modulation was fabricated, and the intensity modulation up to 30 GHz was achieved in a preliminary experiment. A novel oscillator structure; a patch antenna was fabricated on a benzocyclobutene layer stacked on an RTD oscillator, was proposed and fabricated for extraction of output power without using Si lens. The RTD oscillated at ~510 GHz, and an output power of ~40 μW radiated in the upward direction without the Si lens. A wide frequency tunable RTD oscillator using varactor diode was realized. A wide tuning range of ~11% (70 GHz) of the center frequency of 655 GHz was achieved by changing the depletion-layer capacitance of the varactor diode with a DC sweep from ?4 to +0.5 V. THz detectors with high current sensitivity are required for high speed communication. We fabricated a short-gate InGaAs HEMT detector integrated with broadband bow-tie antenna, and achieved current sensitivity of ~5 A/W at 280 GHz. Higher current sensitivity is expected by a HEMT with good subthreshold characteristics.

9483-3, Session 4

Chip scale polarization rotator on SOI for mid-IR: design and analysis *(Invited Paper)*

B. M. A. Rahman, City Univ. London (United Kingdom); Ajanta Barh, Ravi K Varshney, Indian Institute of Technology Delhi (India); Bishnu P. Pal, Mahindra Ecole Centrale (India)

We report design methodology for realizing a compact and efficient mid-IR wavelength polarization rotator (PR) on silicon-on-insulator (SOI) by exploiting power coupling between the fundamental transverse modes of a slot and a strip waveguide (WG)-based directional coupler. Our rigorous numerical investigations revealed that significant power coupling can take place between the fundamental TE and TM modes of the structure owing to their large structural asymmetry and high modal hybridness. As an example, we optimized the structure for efficient performance at 3 μm wavelength at which the maximum power coupling efficiency as high as 90% is feasible within a device length of ~ 536 +m only. Further, suitability of its fabrication is confirmed by calculating fabrication tolerances. Additionally, operational band-width is also studied

9483-10, Session 4

Compact THz receivers *(Invited Paper)*

Thomas W Crowe, Eric W. Bryerton, Jeffrey L. Hesler, Virginia Diodes, Inc. (United States)

Heterodyne receivers based on Schottky barrier diodes offer excellent performance for a range of scientific and commercial applications, including atmospheric studies, plasma diagnostics, communications, imaging and test & measurement systems. These receivers have excellent sensitivity and bandwidth and operate at room temperature. This paper will describe VDI's efforts to fundamentally reduce the size and weight of these receivers so that they can be used in a wider variety of applications. The talk will focus on the development of a W-Band receiver for a NASA cubesat and a ~300GHz receiver for the ITER ECE system. These receiver modules are highly integrated and their volume is greatly reduced from previous state-of-the-art, without sacrificing performance. The new integration technology can be extended to frequencies as high as several terahertz and should result in systems that have greater reliability and lower manufacturing costs.

9483-11, Session 4

Radar system components to detect small and fast objects

Axel Hülsmann, Christian Zech, Mathias Klenner, Axel Tessmann, Arnulf Leuther, Michael Schlechtweg, Oliver Ambacher, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany); Daniel Lopez-Diaz, Lantiq A GmbH (Austria)

Small and fast objects, like bullets of caliber 4.5 to 8 mm, fired from guns like AK-47, can cause serious problems to aircrafts at asymmetric warfare. Especially slow and big aircrafts, like heavy transport helicopters are an easy mark of small caliber hand fire weapons. These aircrafts produce so much noise, that the crew often cannot recognize an attack unless important systems of the aircraft fail. This is just one of many scenarios, where the detection of fast and small objects is desirable. Another similar scenario is the collision of space debris particles with satellites.

To detect such objects by a radar system, several issues have to be taken into account. First of all, the radar equation, which calculates the maximum range, has to be interpreted carefully. As the bullet diameter is in the order of or smaller than the radar wavelength, the radar cross section (RCS) of a sphere is no longer only a function of geometry. Assuming a 5 mm sphere the RCS decreases with the power of 4 by the wavelength. Increasing the frequency beyond 16 GHz enters the so called Mie region, where the RCS is hard to predict caused by interference effects. Further increasing the frequency decreases the Mie effect. Not till then a frequency of 190 GHz is reached, the instable Mie region is left and a stable RCS of -47 dBsm can be assumed.

At our contribution we will also focus on extreme linear and fast chirp generation with high bandwidth for FMCW-radars. Also we will present results on MMICs we have developed for radar applications at W-Band (75-110 GHz) and H-Band (220 – 325 GHz). First experimental results will be also presented.

9483-12, Session 4

Optical simulation of terahertz antenna using finite difference time domain method

Chao Zhang, Zoran Ninkov, Gregory J. Fertig, Rochester Institute of Technology (United States); Andrew P. Sacco, J. Daniel Newman, Kenneth D. Fourspring, Exelis Geospatial Systems (United States); Zeljko Ignjatovic, Univ. of Rochester (United States); Paul P. K. Lee, IEEE (United States); Judith L. Pipher, Craig W. McMurtry, Jagannath Dayalu, Univ. of Rochester (United States)

Terahertz science is a promising and rapidly developing research field. However, solid state terahertz detectors of high performance are still needed. For MOSFET terahertz detectors, since the physical dimension of FET structure is much smaller than the wavelength, an antenna within each pixel is required in order to couple more incident radiation into the detector. In this paper, a software package, Lumerical FDTD solutions, is used to optimize the terahertz antenna design. Effects of various parameters have been explored and the ultimate goad is to have broadband antennas that work efficiently over desired frequency bands. Generally, the transmission/absorption characteristics of bowtie antenna are demonstrated. Upon comparison with more realistic aluminum drude model, perfect electrical conductor (PEC) is verified to be an accurate enough and computationally efficient model for the antenna material. Because PEC material is not absorbing, a mathematically equivalent resistor is added into the system serving to transform incident terahertz energy. After some tests, it is clearly indicated that antenna arrays of smaller pixel pitch, i.e. more units within a fixed area, would grant the system more power to control the incident light. Different from isolated dipole/bowtie antennas, the simulation results demonstrate that antennas on silicon substrate exhibit a larger resonant wavelength than that predicted from the simple half wavelength theory. We get a relationship of very high linearity between three different antenna lengths and their corresponding resonant wavelengths. Some other effects and factors, like fat bowtie, boundary condition, polarization, have also been checked. The knowledge obtained from all these explorations is applied in the design of our new generation detector detector for 215GHz.

9483-13, Session 5

Metasurface induced terahertz transparency and absorption *(Invited Paper)*

Weili Zhang, Oklahoma State Univ. (United States)

Plasmonic metamaterials have recently allowed the observation of the quantum phenomenon of electromagnetically induced transparency (EIT) as a result of the near-field coupling effect between a bright and a dark resonator, where the destructive interference of the resonance modes delivers a sharp window of nearly perfect transmission within a broad absorption band. The EIT effect drastically modifies the dispersive properties of an otherwise opaque medium. In contrast to the destructive interference of the coupled EIT resonators, a constructive interference of different excitation pathways would lead to a new interesting phenomenon known as electromagnetically induced absorption (EIA). Instead of a pronounced transparency window, a sharp absorption resonance is induced in the EIA system. Here, we present experimental demonstrations of the metasurface analogues of EIT and EIA in near-field coupled subwavelength terahertz systems. By use optical photodoping and superconducting media, we also report active switching of the EIT analogue.

9483-14, Session 5

Optical parameters of ZnMgO/ZnO core-shell structures in THz regime

Anas Mazady, Abdiel Rivera, Kiarash Ahi, Mehdi Anwar, Univ. of Connecticut (United States)

Terahertz (THz) optical parameters of Zn1-xMgxO/ZnO core-shell (CS) structures with different Mg mole fractions at the core, namely 2%, 5%, and 10% are determined using THz time domain spectroscopy (THz-TDS) - a noncontact optical probe. In contrast to the most reports of core-shell structures in the form of protruding nanowires (NWs) perpendicular to the axis of the core, we report co-axial core-shell structures. Co-axial core-shell ZnMgO/ZnO structures have potential use in efficient solar cells, gas sensor, and UV detectors leveraging heterostructures of increased junction area, quantum confinement, and reduced dimensionality.

The THz-TDS setup employed a commercial mode locked Ti:sapphire laser that generates 100 fs pulses with a repetition rate of 80 MHz and a 30V bias was applied at the feed of the emitter antenna. CS structures with 10% Mg at the core (CS10) has the highest measured refractive index in the 1-2 THz range, being n=2 at 1.5 THz, followed by the 5% (CS5, n=1.1 at 1.5 THz) and 2% (CS2, n=0.9 at 1.5 THz) Mg mole fraction samples. This is attributed to increased delay of the transmitted THz pulse resulting in a greater phase shift. Higher absorption coefficient is observed for CS structures with higher Mg mole fraction at the core which is consistent with Mazady et al. reporting similar observations for 1-D nanowires [1]. The real part of the complex dielectric constant for CS structure was found to be higher for higher Mg mole fraction, being proportional to the square of the refractive index as expected. The measured real dielectric constant was 4 for CS10, 1.1 for CS5 and 0.35 for CS2 at 1.5 THz. The imaginary part of the complex dielectric constant increased for high Mg sample, being 0.007 for CS10, 0.0065 for CS5, and 0.006 for CS2, that are proportional to the product of absorption coefficient and refractive index.

References

[1] Anas Mazady, Abdiel Rivera, and Mehdi Anwar, “Optical Parameters of Zn1-xMgxO Nanowires in THz Regime”, Solid State Electronics, vol. 101, pp. 8-12, Nov 2014.

9483-15, Session 5

Tuning of terahertz metamaterials’ resonances via near field coupling *(Invited Paper)*

Abul K Azad, Dibakar R Chowdhury, Hou-Tong Chen, Antoinette J Taylor, Center for Integrated Nanotechnologies (United States)

Electromagnetic metamaterials (MMs) consisting of highly conducting sub-wavelength metallic resonators enable many unusual electromagnetic properties at designed frequencies which are not permissible with the naturally occurring materials. The electromagnetic properties of metamaterial are typically controlled by the clever design of the MM unit cell, often termed as meta-molecule, consisting of metallic split ring resonators (SRRs) or meta-atoms. The near field coupling between meta-atoms plays a vital role in tuning the natural resonances of individual SRR and, therefore, has the ability to modify the far-field radiative properties significantly. It is shown that near field coupling between the meta-atoms could lead to resonance tuning, mode splitting, and ultrafast switching in passive and active resonators. In this article, we present a brief review on tuning the metamaterial properties by active and passive manipulation of near field coupling between neighboring split ring resonators.

9483-16, Session 5

Phase characteristics of subwavelength antenna elements for efficient design of terahertz frequency and millimeter-wavelength metasurfaces

Richard J. Williams, Andrew J. Gatesman, Univ. of Massachusetts Lowell (United States); William E. Nixon, National Ground Intelligence Ctr. (United States)

In this paper we investigate the effects of subwavelength antenna resonator element dimensions on the anomalous reflection properties of metasurfaces operating in the millimeter-wavelength and terahertz frequency regions. Such two-dimensional structures are finding uses as flat optics in a variety of applications including beam steerers, reflectarrays, and broadband, polarization-independent radar absorbers. Numerical simulations were performed to characterize the reflection phase-shift of rectangular resonators of varying dimensions for efficient metasurface and reflectarray design. We show that antenna elements with deeply-subwavelength thickness provide the largest total phase variation and therefore present a viable metasurface design methodology for a variety of high frequency applications.

9483-33, Session 5

Sub-THz materials measurements based on low loss corrugated waveguides *(Invited Paper)*

Emile de Rijk, Alessandro Macor, SWISSto12 SA (Switzerland)

Applications that make use of electromagnetic signal beyond microwaves are becoming the game-changing ingredients in a large variety of markets. Automotive radars, 5G telecommunications, food inspection imaging, Magnetic resonance spectrometry, aquametry in pharma or paper industry and others are nowadays pushed toward the Terahertz regime.

Accurate permittivity measurements are necessary to provide scientists and engineers with valuable information to properly and reliably incorporate dielectric materials into application designs and for QC during production.

A material may have several dielectric mechanisms or polarization effects that contribute to its overall permittivity. In particular, atomic and electronic mechanisms affecting the permittivity are relatively weak, and usually constant over the low frequency side of the microwave region. As frequency increases towards Terahertz these mechanisms start to play a major role leading very often to pronounced frequency dependences.

Several solutions used currently at microwave frequencies have been proposed with mitigated success for Terahertz spectroscopy. Difficulties being generated by very thin low loss samples, very high loss samples, sample preparation, measurement set-ups and measurement calibration.

To encompass issues of fundamental rectangular waveguides at sub-THz frequencies, SWISSto12 has developed compact low-loss corrugated waveguide nowadays applied in different applications such as Dynamic Nuclear Polarization NMR and on-wafer probing.

In particular in this work, the advantages of a novel concept called Material Characterization Kit (MCK) recently introduced by SWISSto12 will be presented. The device uses low-loss corrugated waveguide propagating an HE11 EM-mode as fixture for the materials under test. MCK is directly connected to frequency extender modules of VNAs. The MCK provides a quick, reliable and calibrated way to extract dielectric proprieties from S-parameter measurements. A benchmark to other techniques such as TDS will also be presented.

9483-17, Session 6

Extreme THz nonlinearities: high-harmonic generation, dynamical Bloch oscillations and interband Zener tunneling in bulk semiconductors *(Invited Paper)*

Christoph Lange, Olaf Schubert, Matthias Hohenleutner, Fabian Langer, Benedikt Urbanek, Univ. Regensburg (Germany); Ulrich Huttner, Daniel Golde, Philipps-Univ. Marburg (Germany); Torsten Meier, Univ. Paderborn (Germany); Mackillo Kira, Stephan W. Koch, Philipps-Univ. Marburg (Germany); Rupert Huber, Univ. Regensburg (Germany)

Resolving the dynamics of ultrafast charge transport in strongly biased semiconductors is key to understanding coherent processes in solid-state physics, and lies at the heart of future high-speed electronics and electro-optics. We use intense, phase-locked, few-cycle terahertz (THz) pulses at photon energies far below electronic interband resonances as a precisely adjustable alternating bias, far exceeding dc breakdown voltages. These (multi-) terahertz transients centered at 30 THz (left inset) with peak fields of 72 MVcm-1 drive the coherent interband polarization and dynamical Bloch oscillations in semiconducting gallium selenide. The dynamics encompass the generation of strong high-harmonic transients (right inset), spanning the entire terahertz-to-visible spectral domain between 0.1 and 675 THz (main panel) in a single, phase-locked pulse. Phase and amplitude of high-harmonic components can be adjusted via the carrier envelope phase of the driving pulse which controls the interference of multiple interband ionization channels. Microscopic calculations reproduce the polarization response over the large spectral range covering almost 13 optical octaves. Our experiments establish a new field of light-wave electronics exploring charge transport at optical clock rates. Furthermore, we explore high-field transport at 1 THz exploiting the near-field enhancement in metamaterials which enables quasi-static biasing of undoped gallium arsenide at atomically strong field amplitudes. Nonperturbative THz nonlinearities and an interband Zener tunneling rate exceeding previously reported values by 10 orders of magnitude may inspire future THz-rate electric circuitry at the interface of THz optics and electronics.

9483-18, Session 6

A review on THz characterization of electronic components and a comparison of THz imaging characterization with other techniques *(Invited Paper)*

Kiarash Ahi, Navid Asadizanjani, Sina Shahbazmohamadi, Mark Tehranipoor, Mehdi Anwar, Univ. of Connecticut (United States)

Many materials in THz spectral region have unique spectral fingerprints. THz radiation, able to penetrate most of nonmetallic materials allows THz spectroscopy to be used to image the interior structures and constituent materials of wide variety of objects including Integrated circuits (ICs) providing an authentication platform to distinguish between authentic and counterfeit electronic components. Counterfeit and authentic ICs are investigated using Menlosystems TERA OSCAT High-speed Terahertz Spectrometer with measurement frequencies up to 3 THz. Back references average refractive indices and absorption characteristics are extracted to distinguish between authentic and counterfeit parts. Spot measurements are correlated to THz imaging of the whole surface of the IC. It is observed that the packaging of counterfeit ICs are not made from homogeneous materials. In particular, it is observed that the variance of the reflected THz from the surface of the counterfeit IC is 2.7065x⟦10⟧^(-4) a.u. while that of the authentic one is 1.1737x⟦10⟧^(-4) a.u. which is less than 45% of the counterfeit one. Also, the difference between the peak and the minimum value of the reflection of surface is 0.076 a.u. for the counterfeit IC while it is 0.061 a.u. for the authentic one.

Other techniques such as X-ray tomography has also been employed for detection of counterfeit ICs. In this talk, the observations from THz imaging are compared to X-ray tomography. X-ray computed tomography is an imaging method which can provide 3D information of the internal structure without the need for de-capsulation of a ICs. Although, it is not physically destructive to the ICs but the effect of X-ray on the functionality of ICs is not yet fully investigated. Therefore, THz imaging is introduced in this paper as a promising tool for physical inspections of ICs and results are correlated with X-ray imaging analysis.

9483-19, Session 6

Solid state THz sources with higher power *(Invited Paper)*

Thomas W Crowe, Steven A. Retzloff, Jeffrey L. Hesler, Virginia Diodes, Inc. (United States)

The most powerful and frequency agile sources of continuous wave power in the frequency range near 1 THz are built with diode based frequency multiplier chains. These sources commonly use a low frequency oscillator, followed by a power amplifier and then a chain of discrete multiplier blocks; most commonly doublers and triplers. Although it is expected that high frequency amplifiers will eventually eliminate the need for high power multipliers, this time has not yet arrived. Thus, the continued development of frequency multipliers is required to meet the current needs of scientists. For example, chemists require very high power sources to achieve dynamic nuclear polarization to greatly enhance the signal in NMR experiments. In this example, a high power solid-state source is required to pump a tube device that will generate the power required. However, there is hope that if the coupling of the power to the sample and power from the solid-state source can each be significantly improved, then the expensive tube device may be eliminated for a certain class of experiments. Another example is radio astronomy where high power local-oscillator sources are needed for array receivers at frequencies of astronomical importance, such as 1.9THz. This paper will overview VDI's recent development of improved sources for these applications. This will include a description of an improved 264GHz for DNP experiments with 90mW output power and an overview of the ongoing development of sources for 1.9THz.

9483-20, Session 7

Nonlinear optical frequency up-conversion broadening terahertz horizons in sensitive detection *(Invited Paper)*

Kouji Nawata, Shin'ichiro Hayashi, Hiroaki Minamide, RIKEN (Japan)

Second-order nonlinear optical wavelength-conversion has been attractive for generating terahertz (THz) wave with high peak-power and for THz-wave detection by up-converting from terahertz wave to near infrared (NIR) light. Especially, the sensitive THz-wave detection working at room temperature expects to open novel applications. ?We have developed sensitive THz detection down to several tens of atto-joule using lithium niobate (LiNbO3) or 4-dimethylamino-N'-methyl-4'-stilbazolium tosylate (DAST) crystals, and a real-time imaging using up-conversion consisting of DAST crystal and InGaAs NIR-imager.

Particularly, LiNbO3 crystal is an eminent nonlinear crystal for converting wavelengths between THz wave and NIR at frequency range from 1 to 3 THz. Mixing THz wave with an intense NIR pump beam in the LiNbO3 provides generation of a signal light at a different frequency because of efficient figure of merit.

Here, we report on a sensitive THz-wave detection based on novel design using a slant-stripe-type periodically poled lithium niobate (PPLN) for practical use. The efficient scheme that two optical waves, the pump and

up-conversion signal beams, propagate collinearly in the PPLN to achieve effective parametric amplification for the signal beam was designed. The PPLN with a poling angle, ? = 20°and a poling period, ? = 29.0 ?m was employed. A master oscillator power amplifier (MOPA) system consisting of a Nd:YAG microchip laser and Nd:YAG optical amplifiers was used as a pump source for both THz-wave generation and detection. Our injection-seeded THz-wave parametric generator (is-TPG) pumped by the MOPA was used as a THz-wave source. Generated THz-wave at 1.6 THz was incident to a PPLN crystal. Coupling energy of THz-wave into the PPLN was controlled by two sets of THz-wave attenuators. One THz-wave attenuator set consists of four thin-film attenuators with different THz-wave transmissions: 30 %, 10 %, 3 %, and 1 %. The sets are useful as single attenuators or in combination as tuned flexibly. Minimum THz-wave detection was achieved down to energy about 100 aJ at the frequency of 1.6 THz. The result leads to a novel THz detector based on fiber and integrated optics with high sensitivity, robustness, and easy handling.

We demonstrated the remarkably sensitive detection by frequency up-conversion exceeding that of a cryogenically cooled bolometer. The nonlinear optical up-conversion detection is promising and broadening THz horizons.

9483-21, Session 7

Laminated materials characterization by terahertz kinetics spectroscopy

Anis Rahman, Aunik K. Rahman, Applied Research & Photonics, Inc. (United States)

Terahertz spectroscopy under high speed acquisition of reflected energy (kinetics spectroscopy) is an effective tool for layered materials' deformation characterization under ballistic impact. An effort is outlined here that is aimed at utilizing the kinetics spectrum for deducing quantities for uniquely describing a deformation event. Additionally, the same technique may be utilized for real-time assessment of trauma or concussion by measuring the helmet wore by an athlete as opposed to diagnosis by a biomarker. Biomarkers are generated in a person based on an individual's genetic and physiological make up; as such the threshold of a biomarker may vary widely from person to person. On the other hand, deformation of a laminated material (e.g., a helmet) is dependent on the nature of impact and projectile; thus can uniquely characterize the impact condition leading to a diagnostic procedure based on the energy received by an athlete due to impact. In this paper we shall outline the calibration process for a given material under ballistic impact and then utilize the calibration for extracting physical parameters from the measured kinetics spectrum. An effort to relate the physical parameters to trauma/concussion conditions will be outlined. Measured kinetics spectra will be used to outline the method and rationale for extending concept to a diagnosis tool. In particular, kinetics spectra were captured from multilayered plates subjected to ballistic hit under experimental conditions. An algorithm was devised to extract deformation (mm) and deformation velocity from which the energy received on the skull was estimated via laws of motion (under non-relativistic considerations). This energy is assumed to be related to actual injury conditions (trauma and/or concussion), thus forming a basis for diagnosis.

9483-22, Session 7

Experimental determination of terahertz atmospheric absorption parameters

David M. Slocum, Thomas M. Goyette, Robert H. Giles, Univ. of Massachusetts Lowell (United States); William E. Nixon, National Ground Intelligence Ctr. (United States)

The terahertz frequency regime is often used as the 'chemical fingerprint' region of the electromagnetic spectrum since many molecules exhibit a dense selection of rotational and vibrational transitions. Water is a major component of the atmosphere and since it has a large dipole moment the propagation of terahertz radiation will be dominated by atmospheric effects. This study will present the results of high-resolution broadband measurements of the terahertz atmospheric absorption and detail the technique for directly measuring the pressure broadening coefficients, absolute absorption coefficients, line positions, and continuum effects. Differences between these measured parameters and those tabulated in HITRAN will be discussed. Once the water vapor absorption was characterized, the same technique was used to measure the same line parameters for methanol, a trace gas of interest within Earth's atmosphere. Methanol has a dense absorption spectrum in the terahertz frequency region and is an important molecule in fields such as environmental monitoring, security, and astrophysics. The data obtained in the present study will be of immediate use for the remote sensing community, as it is uncommon to measure this many independent parameters as well as to measure the absolute absorption of the transitions. Current models rely on tabulated databases of calculated values for the line parameters measured in this study. Differences between the measured data and those in the databases will be highlighted and discussed.

9483-23, Session 7

Possibility of the detection and identification of substance at long distance using the noisy reflected THz pulse under real conditions

Vyacheslav A. Trofimov, Svetlana A. Varentsova, Vladislav V. Trofimov, Lomonosov Moscow State Univ. (Russian Federation)

We show possibility of the detection and identification of substance at long distance (several metres, for example) using the THz pulse reflected from the object under the real conditions: at room temperature and humidity about 70%. The main feature of this report consists in a demonstration of the detection and identification of substance using the computer processing of the noisy THz pulse. Amplitude of the useful signal is less than the amplitude of a noise. Nevertheless, it is possible to detect "fingerprint" frequencies of substance if both these frequencies are known and the SDA method is used together with new assessments for probability estimation for presence of detected frequencies. Current results show feasibility of using the THz pulsed spectroscopy for the counter-terrorism problem.

9483-24, Session 7

THz magneto-photoresponse spectroscopy of HgTe based quantum well (gapped Dirac type electronic dispersion)

Mehdi Pakmehr, Univ. at Buffalo (United States); Christoph Bruene, Laurens W. Molenkamp, Julius-Maximilians-Univ. Würzburg (Germany); Bruce D. McCombe, Univ. at Buffalo (United States)

The Dirac-like electronic dispersion relation (linear energy vs. momentum) in solids is a topic of current interest in the scientific community. This unique linear dispersion could be beneficial for the design of more efficient devices for both electronic and optoelectronic purposes. We have used THz magneto-photoresponse spectroscopy to probe the gapped Dirac-like dispersion relation of the two-dimensional electron gas of HgTe quantum wells with well width (6.1 nm) such that the topmost valence and conduction bands have the conventional band alignment of found in zinc blende direct gap semiconductors. We used THz laser radiation at frequencies ?=2.4 and 1.83 THz to explore the electronic properties of charge carriers at high Fermi energies (130 ~ 160 meV) at cryogenic temperatures. I will describe the experiments and how we have been able to extract important electronic parameters of electrons in this system from the THz magneto-photoresponse signal, including the g-factor tensor components, the effective mass and the so-called Rashba parameter (?R) . I

will also present our findings about THz magneto-thermoelectric effects for this system from photovoltage measurements in high magnetic fields.

9483-25, Session 8

Room temperature terahertz detectors and their applications *(Invited Paper)*

Jian Chen, Xuecou Tu, Lin Kang, Biaobing Jin, Peiheng Wu, Nanjing Univ. (China)

Terahertz (THz) detector working at room-temperature (RT), consisting of a Nb5N6 thin film microbridge and a dipole planar antenna, is reported. Due to the high temperature coefficient of the resistance (TCR), which is as high as -0.7% /K, of the Nb5N6 thin film, such an antenna-coupled microbolometer is quite suitable for detecting THz signals. Previously, THz detectors working at 0.1 THz have been reported. Here, the results around 0.3 THz will be presented.

The detector consists of a gold dipole planar antenna and a microbridge, which is the core element and is made of properly patterned Nb5N6 film. The software named HFSS is used to carry out numerical simulations for this antenna structure and to optimize the sizes. In the process of Nb5N6 microbolometer fabrication, a SiO2/Si (100) combination substrate is used, where SiO2 with 100 nm thick, is deposited by thermal oxidation on Si (100) substrate with high resistivity (ρ > 1000 Ω•cm). Such a combination is chosen because of its low loss at THz frequencies and ease of fabricating an air-bridge. Then, we used radio frequency (RF) magnetron sputtering to deposit a Nb5N6 film (120 nm thick). The film was patterned into microbridges using photolithography and reactive ion etching (RIE). The dipole antenna was then integrated with the Nb5N6 microbridge by depositing a 5-nm-thick aluminum film firstly, a 220-nm-thick gold later, and then pattern into the right shape and size as designed by the software. Finally, an air-bridge, which reduces the effective thermal conductance of the substrate to further enhance the responsivity, was formed under the Nb5N6 microbridge by etching 1 μm of the Si part of the substrate.

The DC responsivity at RT, calculated from the measured current-voltage (I-V) curve of the Nb5N6 microbolometer, is about -760 V/W. A typical noise voltage as low as 10 nV/√Hz yields a noise equivalent power (NEP) of 1.3 x 10^-11 W/√Hz. The best measured RF responsivity at 0.28 THz, is about 580 V/W, which corresponding NEP of 1.7 x 10^-11 W/√Hz.

Using above detectors, an active imaging system at 0.22 THz has been constructed using a Cassegrain reflector with the diameter of 30 cm. The special resolution of about 1.41 cm is obtained. Also, this work could offer a candidate to develop a large scale focal plane array (FPA) with simple technique and low cost. The details will be discussed in the presentation.

9483-26, Session 8

Performances of THz cameras with enhanced sensitivity in sub-terahertz region

Naoki Oda, Tsutomu Ishi, Seiji Kurashina, Takayuki Sudou, Takao Morimoto, Masaru Miyoshi, Kohei Doi, Hideki Goto, Tokuhito Sasaki, NEC Corp. (Japan); Goro Isoyama, Ryukou Kato, Akinori Irizawa, Keigo Kawase, The Institute of Scientific and Industrial Research (Japan)

Two types of terahertz (THz) cameras with an enhanced sensitivity in sub-THz region are developed, which incorporates 640x480 or 320x240 uncooled microbolometer-type THz focal plane array (FPA) with a pixel pitch of 23.5 μm. The pixel in the THz-FPA has such a structure that an area sensitive to electromagnetic wave is suspended above read-out integrated circuit (ROIC). Thin metallic layer is formed on the top of the sensitive area, while thick metallic layer is formed on the surface of ROIC. The structure composed of the thin metallic layer and the thick metallic layer behaves as an optical cavity.

The THz-FPA has the new pixel structure which has several times longer optical-cavity length than the conventional pixel has, by forming a thick SiN layer (ca. 7 μm thick) on ROIC. The extended optical-cavity structure is favorable for detecting electromagnetic wave with longer wavelength. Consequently, the Minimum Detectable Power per pixel (MDP) is improved ten times in sub-THz region, especially 500-600 GHz. This paper presents wavelength dependences of MDP values for the conventional THz-FPA and THz-FPA with the new pixel structure.

Specification of THz camera which incorporates THz-FPA with the extended optical-cavity structure is summarized. Finally, sub-THz images of both transmission and reflection are presented, using a 500 GHz source, a collimator lens, Galvano mirrors, two wire grids and a quarter-wave plate. The advantage of this imager is that a reflection image of a sample is taken from the frontal side of the sample, so that the image is hardly deformed.

9483-29, Session 8

Robust identification of concealed dangerous substances using THz imaging spectroscopy

Arthur D. van Rheenen, Magnus W. Haakestad, Norwegian Defence Research Establishment (Norway); Helle E. Nystad, Norwegian Univ. of Science and Technology (Norway)

The ability of THz radiation to penetrate common packaging materials makes it well suited to detect unusual or suspicious shapes as well as to identify dangerous and/or illegal substances. In all detection and identification schemes false alarm rates have to be sufficiently low and specificity has to be sufficiently high for the schemes to be used operationally – this is what we mean by robustness. The aim of this work is to identify schemes or algorithms that match measured THz spectra with library-stored spectra to robustly identify the mentioned substances.

We consider two degrees of freedom in our search for a robust algorithm: which spectral characteristic to choose and how to measure distance between the measured and library-stored characteristic. We perform THz-spectroscopy in the time-domain and calculate the raw spectrum through a Fourier transform. However, the raw spectrum may not be the best characteristic to choose for identification – absorbance and its frequency derivative are considered as alternatives. As to what metric to use to compare two THz spectra we have previously explored spectral angle mapping (SAM) [1]. In this work we investigate the merits and pitfalls of using principal component analysis (PCA) and compare results with the mentioned SAM method.

The THz setup is based on a fiber-coupled time-domain spectroscopy system pumped by a 100-fs fiber laser. Images are obtained by scanning the samples through the THz beam by using an x-y stage.

Analysis is performed on measurements taken on a range of proxies for explosives and drugs and under a number of measurement conditions. We are especially concerned with measuring under realistic conditions, where the samples are hidden beneath barriers and measurements are performed in ambient air. Post-processing of raw data is limited to Blackman-Harris windowing of the time-domain signal – water-vapor lines and background increase of absorbance caused by scattering is not removed from the sepctra.

[1] Terahertz imaging spectroscopy – towards robust identification of concealed dangerous substances, Arthur D. van Rheenen and Magnus W. Haakestad, IRMMW & THz 2014, Tucson, 22 – 26 September 2014.

9483-30, Session 8

Dark field THz camera imaging measurements, 200 GHz to 400 GHz

Andrew P. Sacco, J. Daniel Newman, Exelis Geospatial Systems (United States); Paul P. K. Lee, Univ. of Rochester (United States); Kenneth D. Fourspring, John H. Osborn, Robert D. Fiete, Exelis Geospatial Systems (United States); Mark F. Bocko, Zeljko Ignjatovic, Judith L. Pipher, Craig W. McMurtry, Xi-Cheng Zhang, Jagannath Dayalu, Univ. of Rochester (United States); Katherine Seery, Chao Zhang, Zoran Ninkov, Rochester Institute of Technology (United States)

Exelis Geospatial Systems and its CEIS partners at the University of Rochester and Rochester Institute of Technology are developing an active THz imaging system for use in standoff detection, molecular spectroscopy and penetration imaging. The current activity is focused on developing a precision instrument for the detection of radiation centered on atmospheric windows between 200 GHz and 400 GHz (available sources). A dark field camera is developed to image the scattered energy produced from actively illuminating objects with semi-coherent non-ionizing radiation. The optical prescription consists of a catadioptric f/n 1.43, 1-to-1 imager with an aperture of 0.455 m intended to achieve a resolution of 3.0 mm (200 GHz) at a standoff distance of 1.0 m. The primary goal of the initial system development is to produce a precise scientific instrument for THz technology development positioned in the electromagnetic spectral range between 188 GHz and 7.0 THz. Scatter image measurements are presented in order to verify image formation as well as estimate the instruments ability to penetrate materials.

9483-27, Session PThu

MCT as sub-terahertz and infrared detector

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Development of infrared (IR) and sub-terahertz (sub-THz) radiation detectors at the same sensitive elements on the base of mercury-cadmium-telluride (MCT) are reporteded. Bi-color un-cooled and cooled to 78 K narrow-gap MCT semiconductor thin layers grown by liquid phase epitaxy or molecular beam epitaxy procedure on CdZnTe or GaAs high resistivity substrates with bow-type antennas were considered both as sub-THz direct detection bolometers and 3 to 10 um IR photoconductors. For characterization of the effective receiving area of the antenna-coupled MCT hot electron bolometer the deconvolution method was used with detecting signal obtained at the narrowest waist of the beam cross-section, integration of 2-D field distribution of the incident Gaussian beam and the spatial response of the antenna-coupled detector. It was shown that the effective receiving area calculated is about 5.7 square mm and the detector physical area is 39.5 % of this figure. Noise equialent power NEP atfrequancy 140 GHz in n-type bolometers reaches NEP (300K) ~ 5*10^-10 and NEP (78K) ~ 3*10^-9 W/Hz^1/2. Degradation of NEP at temperature decease in n-type detectors is explained by different temperatures dependences of components introducing different temperature contribution in sub-THz sensitivity. The same sensitive layers with antennas used as IR photoconductor showed the responsivity at T = 78 K and 300 K with signal-to-noise ratio S/N ~750 and ~50 respectively under the globar illumination (after infrared monochromator with spectral resolution of ~0.2 um). Images in sub-THz spectral region with these MCT sub-THz bolometers were obtained.

9483-31, Session PThu

Inspection of mechanical and electrical properties of silicon wafers using terahertz tomography and spectroscopy

Thomas Arnold, Wolfgang Mühleisen, Johannes Schicker, Christina Hirschl, Raimund Leitner, Carinthian Tech Research AG (Austria)

Two different THz applications in the semiconductor industry were explored and validated against established reference measurement techniques and simulations. The first application investigated the possibility of measuring mechanical properties of silicon wafers. Time-domain THz tomography mapping scans were carried out to measure wafer thickness and flatness, both in the native state and under different external mechanical loads. These measurements were carried out for a variety of wafers, and the ensuing deformation maps used to validate newly developed numerical simulation models wafer deformation, and vice versa. In the second part of this paper, carrier dynamics of optically injected charges were investigated by THz spectroscopy. THz pump/probe measurements were carried out in transmission and reflection arrangements on silicon wafers illuminated by a metal halide light source. The light source generates free charge carriers in the semiconductor material that affect the transmission and reflection properties of the semiconductor material. The results of the THz measurements are compared to established standard techniques, like microwave-detected photo-conductance decay (MWPCD) or quasi-steady-state photo conductance (QSSPC) measurements. The defective areas identified with the THz measurements are in good agreement with the defective areas identified by the reference methods. A common benefit of time-domain THz measurements is that the wafer thickness, which is an important measure for the interaction volume of the THz radiation with the semiconductor material, can be calculated from the time-domain signals. The results indicate that THz spectroscopy and imaging can be valuable tools for defect analysis and quality control of silicon wafers, especially since the measurement is fully contact-free and can determine electrical properties within a single modality.

9483-32, Session PThu

Variation of ZnMgO properties upon growth technique in THz spectrum

Abdiel Rivera, Anas Mazady, Kiarash Ahi, Mehdi Anwar, Univ. of Connecticut (United States)

Terahertz (THz) index of refraction, dielectric constant, and conductivity of wurtzite Zn1-xMgxO nanowires (NWs) with Mg mole fraction of 7% via sonochemical are determined using THz time domain spectroscopy (THz-TDS). The results are compared with ZnO and ZnMgO NWs with 10% Mg mole fraction grown using metal organic chemical vapor deposition (MOCVD). The successful growth of Zn1-xMgxO with wurtzite structure at low temperature permits realization of the growth of heterostructures, quantum well, nanowires and nanorods on flexible substrates providing lower cost, optical and carrier confinement necessary in advanced light emitting diodes (LEDs), laser diodes (LDs) and high efficiency solar cells.

A Menlo TERA K15 system was employed to carryout THz-TDS using a 100 fs laser with a repetition rate of 80 MHz fitted to excite a photoconductive dipole antenna onto GaAs, and measuring the THz signal at the detector crystal. The FFT of the sample shows absorption of THz corresponding to moisture in air in the range of 0.3 – 0.7 THz, as measurements were performed at atmospheric conditions, while no phonon interaction associated to E2 was detected in the case of ZnO and ZnMgO NWs at 2.98THz. Index of refraction (n) was n = 0.93 in the frequency range of 0.5-1.1THz, that increased to n = 1.22 for frequencies above 1.24 THz (n = 1.1 and 1.22 for ZnO and Zn0.9Mg0.1O, respectively). The variation in refractive index along the THz spectrum, when compared with NWs grown using MOCVD, is attributed to the non-uniformity of Mg mole fraction due to the random distribution of the cavity effects in sonochemical synthesis. The non-uniform Mg incorporation is also noticed under energy dispersive spectroscopy and photoluminescence spectroscopy. Similar trend was observed for the absorption and real part of the complex permittivity in the THz spectrum extending from 0.5 THz to 2 THz.

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9484-1, Session 1

Compressive sensing imaging for general SAR echo model based on Maxwell's equations

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A general echo model is derived for high resolution synthetic aperture radar (SAR) based on Maxwell's equations. After considering the general echo model in frequency domain, a compressive sensing (CS) matrix is constructed from the random partial Fourier matrices for processing the range CS SAR imaging. Simulations validate the orthogonality of the proposed CS matrix and the CS SAR imaging based on the general echo model.

9484-2, Session 1

Sparsity-based moving target localization using multiple dual-frequency radars

Khodour AlKadry, Fauzia Ahmad, Moeness G. Amin, Villanova Univ. (United States)

In this paper, we consider moving target localization in urban environments using a multiplicity of dual-frequency radars. Dual-frequency radars offer the benefit of reduced complexity and fast computation time, thereby permitting real-time indoor target localization and tracking. The multiple radar units are deployed in a distributed system configuration, which provides robustness against target obscuration. We develop the dual-frequency signal model for the distributed radar system and employ a group sparse scene reconstruction approach to simultaneously provide target location and velocity estimates. Simulation results are provided that illustrate the superior performance of the sparsity-based localization technique over the conventional dual-frequency approach based on Doppler filtering, phase comparison, and multilateration, under both full and reduced data volumes.

9484-3, Session 1

Cross-term free based bistatic radar system using sparse least squares

Rasim A. Sevimli, Ahmet E. Cetin, Bilkent Univ. (Turkey)

Passive Bistatic Radar (PBR) systems use illuminators of opportunity, such as FM, TV, and DAB broadcasts. The most common illuminator of opportunity used in PBR systems is the FM radio stations. Single FM channel based PBR systems do not have high range resolution. In order to enhance the range resolution of the PBR systems algorithms using several FM channels at the same time are proposed. In standard methods, consecutive FM channels are translated to baseband as is and fed to the matched filter to compute the range-Doppler map. Multichannel FM based PBR systems have better range resolution than single channel systems. However superious sidelobe peaks occur as a side effect. In this article, we linearly predict the surveillance signal using the modulated and delayed reference signal components. We vary the modulation frequency and the delay to cover the entire range-Doppler plane. Whenever there is a target at a specific range value and Doppler value the prediction error is minimized. The cost function of the linear prediction equation has three components. The first term is the real-part of the ordinary least squares term, the second-term is the imaginary part of the least squares and the third component is the l1-norm of the prediction coefficients. Separate minimization of real and imaginary parts reduces the side lobes of the range-Doppler map. The third term enforces the sparse solution on the least squares problem. We experimentally observed that this approach is better than both the standard least squares and other sparse least squares approaches in terms of sidelobes. Extensive simulation examples will be presented in the final form of the paper.

9484-4, Session 1

Multi-view TWRI scene reconstruction using a joint Bayesian sparse approximation model

Van Ha Tang, Abdesselam Bouzerdoum, Son Lam Phung, Fok Hing Chi Tivive, Univ. of Wollongong (Australia)

Multi-view or multi-location through-the-wall radar (TWR) imaging enhances stationary target detection and localization by combining multiple data sets acquired from different sensing locations. Collecting data at several vantage points improves imaging visibility, but also leads to prolonged data acquisition time, complex computation, and expensive hardware. Recently, compressed sensing (CS) approaches to urban operations and TWR imaging have shifted to relax constraints on signal sampling schemes and logistic difficulties in data acquisition. To date, most of the existing CS-based TWR imaging methods have been proposed for single-view operation mode where a reduced data set collected from one view point is used to form the scene image. In this paper, we address the problem of multi-view TWR scene reconstruction, incorporating wall-clutter mitigation, under a CS context. We consider the problem where the scene is sensed by deploying the aperture along the front and side walls of an enclosed structure, using different reduced sets of frequencies at each antenna. In the proposed approach, a joint Bayesian sparse approximation framework is employed to estimate the antenna signal coefficients simultaneously, by exploiting the sparsity and correlations among antenna signals. Then, a subspace projection technique is applied to segregate the target coefficients from the wall contributions. Finally, a multi-task linear imaging model is developed to fuse the target coefficients from different views taking into account the inter-view dependencies for reconstructing a composite scene image. Experimental results show that the proposed approach improves reconstruction accuracy and produces a composite scene image in which the targets are enhanced and the background clutter is attenuated.

9484-5, Session 2

Point-spread functions for coded aperture imaging with separable doubly-Toeplitz masks

Michael J. DeWeert, BAE Systems (United States)

The Point-Spread Function (PSF) is a standard tool for assessing the performance of imaging systems, and gives a reliable method for predicting the resolution and contrast of standard optics. For a computational imaging system, such as a coded-aperture camera, PSFs must be computed for the computationally-derived or decoded images. Thus, the PSF is a function of both the aperture code and the decoding algorithms. For large ill-posed images, the computational burden of decoding can be high enough to make extensive testing of PSF-improvements prohibitive. Recent advances in coded-aperture imaging, using Doubly-Toeplitz Masks, have sped up the decoding process by orders of magnitude, making it feasible to use PFS analysis to systematically select improved aperture codes. The shape of the best coded-aperture PSFs shows a very sharp central peak on top of smoothly-varying function with a base width equal to 2X the mask size. This has fundamental implications for the resolution and contrast of lensless coded-aperture imaging. The resolution is unlimited – the PSF can preserve

arbitrarily-sharp features. However, the contrast is limited - the wide base of the PSF causes a minimum-attainable blur that depends on the open-area fraction. Only in the trivial case of a 1-pixel mask can the PSF truly approximate a delta function. While, a general theory of the best-attainable PSFs is still in development, this work shows that the limited contrast is due to the ill-posed nature of the inversion. Thus, it is inherent in the encoding and decoding of extended-scenes, and likely applies to all coded aperture masks. Finally, we show that the PSFs correlate well with human-in-the-loop assessments of quality, and thus provide automatable criteria for coded-aperture selection

9484-6, Session 2

Computational imaging in a multiplexed imager with static multispectral encoding

Johann Veras, Robert R. Muise, Kevin Hines, Abhijit Mahalanobis, Lockheed Martin Corp. (United States); Mark A. Neifeld, The Univ. of Arizona (United States)

We simulate and study various computational techniques for image reconstruction applied to a multiplexed Mid-wave-IR Imager. The imager consists of two arms where one is dedicated to high resolution imaging using a lower resolution Focal Plane Array and the other is a single measurement Multispectral imager which uses dispersive optics. We exploit the compressibility of images to estimate a high resolution image and its corresponding lower resolution multispectral data cube using standard computational techniques.

9484-7, Session 2

Compressive and classical hyperspectral systems: a fundamental comparison

Adi Shay, Isaac Y. August, Adrian Stern, Ben-Gurion Univ. of the Negev (Israel)

Hyperspectral imagery involves capturing and processing tremendous amount of data, which sets sever system resource requirements. This has motivated the application of compressive sensing for different spectroscopic and spectroscopic imager systems. Several new compressive hyperspectral architecture have been designed to stretch the common limitations of classical system. However the application of the compressive sensing framework involves design of system architectures that differ significantly from the conventional ones. Since compressive sensing differ essentially from conventional sensing, it cannot be implemented for hyperspectral imaging by simply modifying one of its units of a conventional hyperspectral system, rather it requires a complete new design. In this work we present a comparison between four compressive hyperspectral architectures to conventional architectures. The compressive hyperspectral sensing compared are CASSI, CHISSS, SLCD and CS HPI SPC systems. Those methods are compared to conventional and whiskbroom and pushbroom scanning hyperspectral imaging techniques. A fundamental comparison between these architectures is presented in terms of acquisition effort (total number of samples captures per datacube), optical throughput, signal to noise ration and optical system volume.

9484-8, Session 2

Compressive spectral polarization imaging with coded micropolarizer array

Chen Fu, Univ. of Delaware (United States); Henry Arguello, Univ. Industrial de Santander (Colombia); Brian M. Sadler, U.S. Army Research Lab. (United States); Gonzalo R. Arce, Univ. of Delaware (United States)

We present a compressive spectral polarization imager driven by a prism which is rotated to different angles as the measurement shots are taken, and a colored detector with a micropolarizer array. The prism shears the scene along one spatial axis according to its wavelength components. The scene is projected to different locations on the detector as measurement shots are taken. Composed of 0 degree, 45 degree, 90 degree and 135 degree linear micropolarizers, the pixels of the micropolarizer array are matched to that of the detector; thus, the first three Stokes parameters of the scene are compressively sensed. The four dimensional (4D) data cube is thus projected onto the two dimensional (2D) FPA. Optimal patterns for the micropolarizer and the colored detector are developed so as to improve the reconstruction inverse problem. The performance of the imager is improved by more than 6dB in PSNR compared with that attained using random codes for the polarizers and filters in one measurement shot. 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. Both computer simulations and hardware implementation are performed.

9484-9, Session 3

Recent results in single-pixel compressive imaging using selective measurement strategies *(Invited Paper)*

Matthew A. Herman, InView Technology Corp. (United States)

Compressive sensing (CS) and its application to imaging (CI) has been an active area of research for the last five to ten years. CI theory permits taking significantly fewer measurements M as compared to the total number of pixels N in a scene. Measurements in a single-pixel camera are usually taken sequentially using a spatial light modulator (SLM). In practice, the patterns displayed on an SLM correspond to rows of an NxN orthogonal sensing matrix. The original theory advocated choosing M of the N rows uniformly at random, which is a universal strategy. However, recent insights have shown better approaches exist that exploit the statistics of classes of images. At the same time, sensing matrices that have a Kronecker product structure (e.g., Hadamard) are particularly attractive since they can be arranged into blocks of rows, where each block contains a unique spatial frequency signature. These types of matrices are well suited to complement a more selective measurement strategy. Moreover, many of these matrices possess fast methods to both compute an NxN transform, as well as to generate individual patterns "on the fly." We outline a new approach called "Partial-Complete Hadamard" sensing, that can choose patterns based on the general statistics of a class of images, or can be adapted to the specific statistics of a scene that is being observed. With this technique we show significant improvement in image quality and reconstruction time as compared to sensing with Hadamard waveforms that are randomly chosen. Besides estimation, this technique can also be used in detection and classification applications.

9484-10, Session 3

L1-PCA video surveillance

Ying Liu, Dimitris A. Pados, Univ. at Buffalo (United States)

We describe for the first time in the literature L1-norm principal-component analysis (PCA) of video frames and demonstrate the utility in background representation and moving object extraction. Optimally calculated maximum-L1-norm frame-sequence projection vectors exhibit remarkable ability to capture consistently present imagery and enable most effective video surveillance. Desired foreground responses are seen even in the presence of an oscillating background and time-varying occlusions. Benchmark comparisons with standard (L2-norm) PCA analytics are included for reference purposes.

9484-11, Session 3

Gradient-based compressive sensing for noise video reconstruction

Huihuang Zhao, Hengyang Normal Univ. (China); Shuxia Li, John Montalbo, Zhijun G. Qiao, The Univ. of Texas-Pan American (United States)

The well-known Nyquist/Shannon sampling theorem that the sampling rate must be at least twice the maximum frequency of the signal is a golden rule used in visual and audio electronics, medical imaging devices and so on. Compressive sensing (CS) is a sampling paradigm that provides the signal compression at a rate significantly lower than the Nyquist rate. CS has successfully been applied in a wide variety of applications in recent years, including photography, shortwave infrared cameras, optical system research, audio and music processing, MRI, etc. For example, an iterative image reconstruction method in X-ray CT was recently developed based on CS. A fast encoding method for Synthetic Aperture Radar (SAR) raw data compressing and reconstruction was also proposed with the CS theory. Although CS achieves good application in most cases, there are still many difficulties for a noise signal processing based on CS theory. In this paper, we will develop a fast gradient-based compressive sensing (FGB-CS) method for noise video. Specially, we will consider the compressive sensing for noise video as a convex optimization problem, and present a gradient-based compressive sensing method to solve it. Moreover, to reduce the computational cost, we will replace the traditional iteration parameter by Lipschitz constant. Experimental results will show the performance of our method.

9484-12, Session 4

Compressive sensing cryptographic analysis

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Lately, there has been a huge interest in compressive sensing as a technology to perform measurements at a lower sample rate than that of the Nyquist frequency. This is very useful in wireless sensor networks applications where data transmission should be reduced at a minimum in order to save power resources. At the same time the privacy and secrecy of the information transmitted through a wireless channel is a problem that needs attention. This security issue is more relevant in applications where sensitive information is being transmitted, as for example in medical wearable devices. In this paper the measurement matrix used in compressive sensing is analyzed in order to evaluate at what level it can be considered as an encryption mechanism. This evaluation is performed by comparing the secrecy that can be achieved with the measurement matrix compared with more traditional encryptions algorithm as AES and Camellia. Results are presented in order to validate that confidentiality of the information is achieved but at a reduced level compared to their traditional encryption counterparts.

9484-13, Session 4

Sparsity-based DOA estimation of coherent and uncorrelated sources using transmit/receive co-prime arrays

Elie BouDaher, Fauzia Ahmad, Moeness G. Amin, Villanova Univ. (United States)

In this paper, we use transmit/receive co-prime arrays for direction finding of mixed coherent and uncorrelated sources based on the concept of sum coarrays. The sum coarray is defined as the set of pair-wise sums of the position vectors of the elements in the transmit and receive apertures. The data measurements from the transmit/receive co-prime array are used to emulate observations at a virtual array, whose element positions are given by the sum coarray corresponding to the co-prime array. A group sparse reconstruction problem is formulated employing multiple snapshots, where each group corresponding to a specific angle of arrival extends across all the time samples. The sum-coarray based approach provides the ability to resolve a higher number of sources than the number of physical antennas. Performance evaluation of the proposed method is conducted using numerical simulations.

9484-14, Session 4

See-through obscurants via compressive sensing in degraded visual environment

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Solutions to Degraded Visual Environment are extremely significant to the safety of aircraft maneuvering and landing. Current approaches focus on building sensors at suitable wavelengths to counter obscurant particle size and density. For example, millimeter wave radar, with its long wavelength, allows effective penetration of most sand or dust particles. However, such solution has limitation with respect to cost, SWaP, and resolution.

This paper proposes a different approach: Instead of building new sensors for each type of obscurants, we focus on extracting hidden information from the raw sensor data via computational imaging techniques. We show that although to the human eye a sensor captures a zero-visibility view of an object through dense obscurants, it is possible to recover the hidden visual information of the object and display to the pilot to aid in landing and maneuvering.

Specifically, we propose a compressive sensing algorithm incorporating a dictionary composed of pose transformation of the targeted object. We will show using the proposed algorithm, it is possible to accurately detect and locate the object of interest in severe Degraded Visual Environment. We will quantify the upper bound of the DVE noise in which the proposed method is effective, as well as the processing speed for real-time processing. The proposed method is agnostic to sensor technologies and therefore can be applied to various sensors including LIDAR, Infrared, or millimeter wave radar in a multi-sensor setting.

9484-15, Session 4

An analysis of spectral transformation techniques on graphs

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In this paper, we will analyze emerging methods for the spectral analysis of graphs, as graphs are currently used to study interactions in many fields from neuroscience to social or sensors networks. There are two main approaches related to the spectral transformation of graphs. The first approach is based on the Laplacian matrix [1]. The graph Fourier transform is defined as the expansion of a graph signal in terms of eigenfunctions of the graph Laplacian. The calculated eigenvalues carry the notion of frequency of graph signals. The second approach is based on the graph weighted adjacency matrix [2], as it expands the graph signal into a basis of eigenvectors of the adjacency matrix instead of the graph Laplacian. Here, the notion of frequency is then obtained from the eigenvalues of the adjacency matrix or its Jordan decomposition. In this paper, we will examine advantages and drawbacks of both approaches [1,2]. Potential challenges and improvements to graph spectral processing methods will be considered as well as the generalization of graph processing techniques in the spectral domain. Its generalization to the time-frequency domain and other potential

extensions of classical signal processing concepts to graph datasets will be considered also. Lastly, we will consider the idea of compressive sensing on graphs.

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9484-16, Session 4

Time-frequency signature sparse reconstruction using chirp dictionary

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Nonstationary signals arise in a broad class of active sensing modalities, including sonar, radar, and ultrasound. They are the preferred type of smart jamming and also characterize many passive sensing problems, such as speech and electromyographic recordings. Time-frequency signal representations (TFSRs) enable separations of nonstationary signals that are mixed in both time and frequency domains, where traditional windowing and filtering based approaches fail to capture or distinguish between individual signal components.

TFSRs are mainly obtained using quadratic time-frequency distributions (QTFDs), generally referred to as Cohen's class, which have their roots in the nonparametric Wigner-Ville distribution (WVD). QTFDs are defined by two-dimensional (2D) kernels which convolve the WVD for interference reduction. The reduced-interference distribution (RID) kernels act on preserving the true signal power terms, referred to as auto-terms, and eliminating, or at least considerably attenuating, the undesired cross-terms, which represent false power concentrations and are generated from the data bilinear lag products underlying QTFDs. Owing to their instantaneous narrowband characteristics and high power concentrations over the joint time-variable (TF) variables, the signatures of a large class of nonstationary signals occupy small regions in the TF domain. In other words, most of the TF domain is vacant. This property casts the signals as sparse in the joint-variable representations and has recently invited sparse signal reconstruction and compressive sensing techniques to play an important role in TF signal analysis and processing.

Missing and randomly sampled nonstationary signals give rise to artifacts in both the time-frequency domain and the ambiguity domain. These artifacts present clutter in the joint-variable domain which obscures the signal components and their instantaneous frequencies. Efforts and attempts to use traditional TF kernels to reduce the clutter along with mitigations of signal cross-terms, which arise due to the bilinear data products underlying QTFDs, have proved ineffective and unsuccessful

In this paper, sparse reconstruction is applied in lieu of QTFDs. We reconstruct time-frequency signature from compressed time samples using chirp dictionary. Chirp atoms have better approximations to the local signal behavior over a dictionary of sinusoidal atoms which have been used previously to exploit the local sparsity of FM signals characterized by their instantaneous frequencies following certain frequency laws. Further, compared to reconstruction techniques using parameterized atoms which also directly operate on the data, the proposed technique does not assume any signal structure and, as such, is able to maintain its desirable performance for a wide class of nonstationary signals.

9484-17, Session 5

Compressive line sensing imaging system using active spatial light modulation devices

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The compressive line sensing (CLS) active imaging system [1] was proposed as an energy efficient alternative to the traditional line-scan based serial image [3]. An experimental prototype was constructed to conduct a series of test tank experiments [2]. As in many other Compressive Sensing imaging applications, the experimental prototype was developed using a Digital Micro-mirror Device (DMD). While the experimental results did provide initial validation of the proposed CLS concept, they, however, revealed some limitations of adopting a passive spatial light modulation (SLM) device such as DMD in such system. Since the whole DMD surface will be illuminated by the laser source, at least 50% of energy will not be utilized in target sensing.

This presentation proposes an approach to mitigating such energy utilization inefficiency. In this regard, an emerging technology – Individually Addressable Laser Diode Array (IALDA) is investigated. IALDA consists of an array of laser emitters whose phase and amplitude can be controlled independently at high speed. IALDA is, therefore, a type of active SLM device. Currently, IALDA is mainly used in laser marking or other printing applications, this work, therefore, represents a first attempt to adopt such technology in CS imaging applications. In the proposed design, the combination of a single laser source and DMD system will be replaced by an IALDA and the front end digital control board. The receiver architecture is unchanged – consisting of a single-element photodetector such as the photomultiplier tube and a data acquisition device. The multi-layered sensing pattern design, the distributed compressive sensing (DCS) based image reconstruction also remain valid. The construction of a prototype system using a commercially-available IALDA printing head will be discussed. The experimental results obtained using this prototype will also be presented.

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9484-18, Session 5

Compressive quantum sensing *(Invited Paper)*

John C. Howell, Gregory Howland, Daniel Lum, Univ. of Rochester (United States)

Compressive sensing utilizes sparsity to realize efficient image reconstruction. It is a valuable processing technique when cost, power, technology or computational overhead are limited or high. In the quantum domain, technology usually limits efficient acquisition of weak or fragile signals. We have used compressive sampling for low-flux laser Radar, photonic phase transitions, high resolution biphoton ghost imaging, 3D object tracking with less than picowatts of power at 14 frames per second, ghost object tracking, wavefunction acquisition, measurement of conjugate observables and high dimensional entanglement characterization. I will discuss how compressive sensing can aid in quantum sensing by discussing two or three of our recent quantum sensing experiments.

9484-19, Session 6

Compressive power spectrum sensing for vibration-based output-only system identification of structural systems in the presence of noise

Agathoklis Giaralis, Bamrung Tausiesakul, Kyriaki Gkoktsi, City Univ. London (United Kingdom)

In recent years various analog-to-information converters (AICs) capable of capturing the salient features of continuous-time signals by sampling at much slower than the Nyquist frequency rate have been theoretically developed and prototyped (e.g. [1,2]). It has been recognized that sensors equipped with such AICs can reduce monetary and energy costs in wireless sensor networks (WSNs), being cheaper and less energy consuming than conventional analog-to-digital converters [3]. This is quite a desirable consideration for the structural design validation, condition assessment and health monitoring of engineering structures (e.g., mid-to-high rise buildings, large-span bridges, offshore platforms for oil and gas exploration, etc.) from structural vibration measurements using battery operated WSNs [4]. In this regard, this paper considers the multi-coset sampling AIC in [5], in conjunction with the deterministic sub-Nyquist sampling patterns derived in [6 and 7] for power spectrum blind sampling to capture the useful "information" (e.g., natural frequencies, peak gains in the frequency domain, and damping ratios) of white noise excited linear damped structural systems directly from noisy compressive vibration (acceleration) measurements. Specifically, the potential of the considered AIC for the task is assessed within a Monte Carlo simulation-based framework involving modelling the underlying analog frequency response functions (FRFs) of the structural systems by means of Auto-Regressive Moving Average (ARMA) filters using standard techniques for spectrum compatible simulation [8]. Simulated sequences of white noise at Nyquist rate are colored via these ARMA filters, contaminated by additive white noise, and compressively sensed by a discrete-time model of the adopted AIC device at various compression rates. Next, power spectral estimation is performed directly to the compressed measurements and, finally, standard techniques for output-only system identification in the frequency domain are considered to extract modal parameters. It is reported that 50% or fewer measurements compared to the Nyquist sampling rate are required to obtain reliable estimates of modal structural properties from compressed sensed signals, even in the case of closely-spaced natural frequencies and extreme white noise contamination. Compared to the recent work in [9] which is based on the random demodulator AIC architecture and considers random sub-Nyquist sampling, the herein approach can treat heavily damped structural systems and its performance is not significantly affected by noise, while it achieves modal parameters extraction directly from compressed measurements (i.e., it bypasses signal reconstruction in the time domain).

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9484-20, Session 6

Multimodal exploitation and sparse reconstruction for guided-wave structural health monitoring

Andrew L. Golato, Sridhar Santhanam, Fauzia Ahmad, Moeness G. Amin, Villanova Univ. (United States)

The presence of multiple modes in guided-wave structural health monitoring (SHM) has been usually considered a nuisance and a variety of methods have been devised to ensure the presence of a single mode. However, valuable information regarding the nature of defects can be gleaned by including multiple modes in image recovery. In this paper, we propose an effective approach for localizing defects in thin plates, which involves inversion of a multimodal Lamb wave based model by means of sparse reconstruction. We consider not only the direct symmetric and anti-symmetric fundamental propagating Lamb modes, but also the defect-spawned mixed modes arising due to asymmetry of defects. Model-based dictionaries for the direct and spawned modes are created, which take into account the associated dispersion and attenuation through the medium. Reconstruction of the region of interest is performed jointly across the multiple modes by employing a group sparse reconstruction approach. Performance validation of the proposed defect localization scheme is provided using both simulated and experimental data for an aluminum plate.

9484-21, Session 6

Seismic Full Waveform Inversion from Compressive Measurements

Ana Ramirez, Gonzalo R. Arce, Univ. of Delaware (United States)

Traditional methods used to acquire 2-D seismic traces require sources and geophones that are uniformly located along a spatial line, using the Nyquist sampling rate. Because of complex geological models of the subsurface, it has been required to use receivers at large offsets which generates very high volumes of data. It makes the exploration process more difficult and particularly expensive. Recently, the emerging paradigm of compressive sensing can be used to capture the structure of the subsurface using less number of sources and receivers. Using this paradigm, the same area of exploration can be imaged requiring less resources (i.e., time and sensors). This work presents the reconstruction of 2-D compressive seismic traces acquired us- ing compressive measurements where the pair of sources and geophones are randomly located along the spatial line. The recovery of the wavefield from compressive measurements is feasible due to the capabilities of the Curvelets on representing wave propagators with only a small set of coefficients. The proposed method first uses the compressive measurements to find a sparse vector representation of each pixel in a 2-D Curvelet dictionary. The sparse vector representation is estimated by solving a sparsity constrained optimization problem using the Gradient Projection for Sparse Reconstruction (GPSR) method. Simulations of the reconstruction of synthetic image gathers illustrate the performance of the proposed method.

9484-22, Session 6

Group sparsity based estimation of nonstationary harmonic signals

Yimin D. Zhang, Villanova Univ. (United States)

Spectrum analysis of speech signals is important for their detection, recognition, and separation. speech signals are nonstationary and time-varying frequencies and, when analyzed over a short time window through, for example, the commonly used short-time Fourier transform, exhibit harmonic spectra, i.e., the fundamental frequencies are accompanied by multiple associated harmonic frequencies. With proper modeling, such harmonic signal components can be cast as group sparse and can be solved using group sparse signal reconstruction methodologies. The consideration of group sparsity allows to achieving the signal sparsity metric to be equal to the actual number of signals at each time instant. In this case, all harmonic components contribute to effective signal detection and fundamental frequency estimation with improved reliabilities and clean time-varying spectra. In addition, the estimation of the slowly time-varying fundamental frequency signatures can be implemented over the analysis window using the structure-aware Bayesian compressive sensing technique, which is known to its capabilities of high-resolution spectrum estimation and flexible signal structure consideration. Such treatment allows nonstationary signal spectrum analysis to be performed with an extended time period to achieve improved signal detectability and enhanced parameter estimations. The proposed technique can be implemented in combination with stationarization or warping for further performance improvement.

9484-23, Session 7

Biomedical sensor design using analog compressed sensing

Mohammadreza Balouchestani, Sridhar Krishnan, Ryerson Univ. (Canada)

In this work, we present an implementation of a low-power biomedical sensor using analog Compressed Sensing (CS) framework for healthy and myopathy surface Electromyography (sEMG) signals that addresses both the energy and telemetry bandwidth constraints of wearable and wireless Body-Area Networks (BANs). This architecture enables continuous data acquisition and compression of healthy and myopathy sEMG signals that are suitable for a variety of diagnostic and treatment purposes. At the transmitter side, an analog-CS framework is applied at the sensing step before analog to digital converter in order to generate the compressed version of the input bio-signal. At the receiver side, a reconstruction algorithm based on Restricted Isometry Property (RIP) is applied in order to reconstruct the original bio-signals form the compressed bio-signals with high probability and enough accuracy. The proposed architecture reduces sampling-rate to 29 % of Nyquist rate, power consumption to 48 %, Percentage Residual Difference (PRD) to 26 %, Root Mean Squared Error (RMSE) to 3 %, and total computation time from 28 to 11.2 seconds.

9484-24, Session 7

Conflict-cost based random sampling design for parallel MRI with low rank constraints

Wan Kim, Yihang Zhou, Jingyuan Lyu, Leslie Ying, Univ. at Buffalo (United States)

In compressed sensing MRI, it is very important to design sampling pattern for random sampling. Variable density (VD) Poisson discs are typically adopted for 2D random sampling in MRI. The basic concept of Poisson disc generation is to guarantee no samples in the circle of a specified radius centered at a target sample. However, it is very difficult to meet such a condition especially in the high density region. Therefore the sampling becomes inefficient. SAKE (simultaneous auto-calibrating and k-space estimation) is one of the parallel MRI reconstruction methods using the correlations among coils. In SAKE, the reconstruction from a randomly undersampled image is formulated as a structured low-rank matrix completion problem. We present an improved random sampling pattern for SAKE reconstruction. The pattern is generated based on a conflict cost with a probability model. The conflict cost measures how many dense samples already assigned are around a target location, while the probability model adopts the generalized Gaussian distribution which includes uniform and Gaussian-like distributions as special cases. Our method preferentially assigns a sample to a k-space location with the least conflict cost on the annulus of the highest probability. To evaluate the effectiveness of the proposed random pattern, we compare the performance of SAKEs using both VD Poisson discs and the proposed pattern. Experimental results for brain data show that the proposed pattern is less sensitive to the increased density and it yields lower normalized mean square error (NMSE) than VD Poisson discs.

9484-25, Session 7

Long-term surface EMG monitoring using K-means clustering and compressive sensing

Mohammadreza Balouchestani, Sridhar Krishnan, Ryerson Univ. (Canada)

Clustering of Long-term surface Electromyography (sEMG) recording aims at recording of the electrical activities produced by muscles which are very useful procedure for treatment and diagnostic purposes as well as for detection of various pathologies. Currently used clustering algorithms for long-term sEMG recording do have their share of drawbacks: 1) Clustering and classification cannot be done in real time for long-term recording and monitoring; 2) Implementing existing algorithms would lead to higher computational costs. These drawbacks motivated us in developing novel optimized clustering algorithm which could easily scan large sEMG datasets of long-term sEMG recording. In this work, we present an advanced K-means clustering algorithm based on Compressed Sensing (CS) in combination with the K-Singular Value Decomposition (K-SVD) method. The proposed algorithm out-performs existing algorithms by achieving a classification accuracy of 99.90 %. This ability allows reducing 17 % of Average Classification Error (ACE) and 11 % Clustering Energy Consumption (CEC).

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9485-1, Session 1

Real time fatigue damage growth assessment of a composite 3 stringer panel using passive thermography *(Invited Paper)*

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Fatigue testing of advanced composite structures is critical to validate both structural designs and damage prediction models. In-situ inspection methods are necessary to track damage onset and growth as a function of load cycles. Passive thermography is a large area, noncontact inspection technique that is used to detect composite damage onset and growth in real time as a function of fatigue cycles. The thermal images are acquired in synchronicity to the applied compressive load using a dual infrared camera acquisition system for full (front and back) coverage. Image processing algorithms are investigated to increase defect contrast areas. The thermal results are compared to non-immersion ultrasound inspections and acoustic emission data.

9485-2, Session 1

Nondestructive evaluation of aircraft coatings with infrared diffuse reflectance spectra

Michael R. Hawks, Air Force Institute of Technology (United States) and Oak Ridge Institute for Science & Education (United States); Kody A. Wilson, Air Force Institute of Technology (United States); Timothy W. C. Zens, Air Command and Staff College (United States); Adam T. Cooney, Hans G. Korth, Air Force Research Lab. (United States)

Aircraft coatings degrade over time, but aging can be difficult to detect until it is too late. This makes it difficult to plan aircraft maintenance schedules, and can lead to aircraft being unexpectedly placed in non-mission capable status. We present a method to evaluate aircraft coatings in situ using infrared diffuse reflectance spectra. Two different types of coatings were artificially aged in an autoclave, and half the samples were used to train the classifier. Spectra were measured using a hand-held diffuse reflectance infrared Fourier transform spectrometer (DRIFTS). One set of 72 samples can be classified as either aged or unaged with 100% accuracy. A second sample set contained samples that had been artificially aged for 0, 24, 48 or 96 hours. Several classification methods are compared, with accuracy better than 98% possible. Classification results based on surface roughness estimates and spatial uniformity of the spectra are also discussed.

9485-3, Session 1

Comparative evaluation of aerospace composites using thermography and ultrasonic NDT techniques

Panagiotis Theodorakeas, Nicolas P. Avdelidis, Eleni Cheilakou, National Technical Univ. of Athens (Greece); Roubini Marini, Hellenic Aerospace Industry S.A. (Greece); Maria Koui, National Technical Univ. of Athens (Greece)

In recent years, the reliability and efficiency of defect detection on aerospace composite structures, after applying Non Destructive Testing and Evaluation (NDT&E) techniques, has gained a wide interest. Smart and non-invasive methods for assessing and monitoring the integrity of a composite structure are essential to both its manufacturing and operational stages, while these techniques are more easily adopted by inspection services when producing reliable results in a prompt manner (real or near-real time results). In the present research work, a study was carried out for the applicability of two NDT techniques, Transient Thermography (TT) and Ultrasound Testing (UT), inspecting different types of composite specimens (i.e. laminated CFRPs, laminated Hybrid FRPs and sandwiched structures), which were consisted of a variety of defect modes. The main aim of this study was to compare the defect detectability produced from each testing configuration and evaluate the efficiency of each method in terms of defect detectability and inspection time. The results of this study showed that all the defects were revealed either by transient thermography or ultrasonic testing, however thermographic analysis can display the acquired results in a more rapid manner. On the other hand UT testing can provide efficient results for deeper probing requiring however longer inspection times.

9485-4, Session 1

A new approach on JPSS VIIRS BCS and SVS PRT calibration

Tung R. Wang, Steve A. Marschke, Michael Borroto, Christopher M. Jones, Christopher Chovit, Raytheon Co. (United States)

Joint Polar Satellite System (JPSS) is an Earth-observing satellite, developed by NASA for the National Oceanic and Atmospheric Administration (NOAA), to measure both global climate changes and key weather variables. The largest instrument aboard JPSS is the Visible Infrared Imaging Radiometer Suite (VIIRS), developed by Raytheon Space and Airborne Systems, which collects radiometric imagery, in visible and infrared wavelengths, of the land, atmosphere, ice and ocean. A Ground Support Equipment (GSE), Blackbody Calibration Source (BCS), was used as an optical simulator to validate the VIIRS emissive band calibration. Another GSE, Space View Source (SVS), was used as an optical simulator to provide zero radiance sources for all VIIRS bands. The temperature of BCS and SVS were monitored by a set of calibrated platinum resistance thermometers (PRT's). The required PRT temperature 1 sigma uncertainty is less than 0.030K. To improve the thermal contact of PRTs to the BCS and SVS bounce plate, the PRT is installed in an aluminum thermal block potted with RTV566 which helps to reduce the thermal stress to the PRT. These PRTs were calibrated using the thermal bath setup from Raytheon Primary Standard Laboratory. The thermal bath temperature was measured using a NIST traceable Standard PRT (SPRT). A single thermal bath fluid was used to cover the calibration temperature range. A process was developed to validate the PRT resistance to be stable under thermal cycles. Detailed calibration setup is described. The PRT calibration uncertainty is estimated and deemed sufficient to support BCS and SVS effective temperature requirements.

9485-6, Session 1

Integration of infrared and optical imaging techniques for the nondestructive inspection of aeronautic parts

Fernando López, UFSC (Brazil); Stefano Sfarra, Univ. degli Studi dell'Aquila (Italy); Clemente Ibarra-Castanedo, Univ. Laval (Canada); Domenica Paoletti, Univ. degli Studi dell'Aquila (Italy); Xavier Maldague, Univ. Laval (Canada)

Non-Destructive Testing (NDT) is defined by the American Society of Non-Destructive Testing (ASNT) as «the determination of the physical condition of an object without affecting that object's ability to fulfill its intended function». The present research work is: a) linked to the modern NDT paradigm, i.e., 'the use of NDTs can fit into several steps of the manufacturing process and, in particular, for the quality control at each level of the manufacturing', and b) focused on the defects detection of a wing component supplied by Mecaer Aviation Group (MAG). The part of a helicopter wing (36 x 17,5 x 2,5 [cm]) inspected contains fabricated defects, i.e., one detachment: 0,74 [cm] in length – <0,01 [cm] in depth, and one crack: 0,17 [cm] in length – ϕ: 0,03 [cm] in thickness – 0,01 [cm] in depth, and was realized using Aluminum Alloy 2024 from SAE Aerospace. The sample was tested choosing two NDT methods falling within classification: optical testing (OT), and infrared and thermal testing (IR). Both groups have the characteristics of full-field and non-contact. However, they are fundamentally different in the sensing and detection mechanisms. OT measures the material mechanical response to stress, whilst infrared thermography (IRT) technique of IR group measures the heat transfer response when an instantaneous or dynamic excitation is applied to the material under study. In particular, this work is based on an integration of digital speckle photography (DSP), holographic interferometry (HI) and IRT NDT techniques. An external excitation (a short or long thermal pulse) was applied to the material surface. Contrasts in the thermal (as in IRT) and/or strain (as in DSP and HI) fields will reveal the presence of the internal defects. Concerning to IRT technique, once the acquisition is performed, the stack of thermal images is then processed with several thermographic signal processing algorithms in order to enhance detection and image quality. The discussion of the results will be based on the detection capabilities of each imaging techniques, their advantages and limitations to inspect aeronautic materials.

9485-7, Session 2

Identification of moisture sources in building assemblies using IRT

Gregory B. McIntosh, Snell Infrared Canada (Canada); Antonio Colantonio, Public Works and Government Services Canada (Canada)

Water, in its various phases, in any environment other than desert (hot or cold) conditions, is the single most destructive element that causes deterioration of building materials and failure of building assemblies. It is the key element present in the formation of mold and fungi that lead to indoor air quality problems. Water is the primary element that needs to be managed in buildings to ensure human comfort, health and safety. Under the right thermodynamic conditions the detection of moisture in its various states is possible through the use of infrared thermography for a large variety of building assemblies and materials. The difficulty is that moisture is transient and mobile from one environment to another via air movement, vapor pressure or phase change. Building materials and enclosures provide both repositories and barriers to this moisture movement. In real life steady state conditions do not exist for moisture within building materials and enclosures. Thus the detection of moisture is in a constant state of transition. Sometimes you will see it and sometimes you will not. Understanding the limitations at the time of inspection will go a long way to mitigating unsatisfied clients or difficult litigation.

Moisture detection can be observed by IRT via three physical mechanisms; latent heat absorption or release during phase change; a change in conductive heat transfer; and a change in thermal capacitance. Complicating the three methodologies is the factor of variable temperature differentials and variable mass air flow on, through and around surfaces being inspected. Building enclosures come in variable assembly types and are designed to perform differently in different environmental regions. Sources for moisture accumulation will vary for different environmental conditions. Detection methodologies will change for each assembly type in different ambient environments.

This paper will look at the issue of the methodologies for detection of the presence of moisture and determination of the various sources from which it accumulates in building assemblies. The end objective for IRT based moisture detection inspections is not to just identify that moisture is present but to determine its extent and source. Accurate assessment of the source(s) and root cause of the moisture is critical to the development of a permanent solution to the problem.

9485-8, Session 2

Evaluation of angle dependence in spectral emissivity of ceramic tiles measured by FT-IR

Chie Kobayashi, Nagahisa Ogasawara, Hiroyuki Yamada, Syunsuke Yamada, National Defense Academy (Japan); Takashi Kikuchi, K-Plus, Inc. (Japan)

Ceramic tiles are widely used for building walls. False detections of delamination are often caused in non-destructive inspection using IR thermography because of the IR reflection from backgrounds, which is associated with high reflectivity, i.e. low emissivity. In the non-destructive inspection using IR thermography for the high buildings, the camera angles have to be changed in order to measure the high wall from the ground. Thus, it is necessary to evaluate the emissivity at various angles. In this study, the effect of angle dependence in spectral emissivity was investigated using FT-IR attached a holding device with variable angles and film heater made of stainless steel.

The measured angles were from 0 to 75 degrees. In addition it is very important to measure the temperature of the surface of test pieces in the investigation of the spectral emissivity. As to ceramic which has low thermal conductivity, it is difficult to measure the accurate surface temperature by thermocouples. Therefore, the temperature was measured by using the combination of a reference sample and IR thermography camera.

According to Maxwell's electromagnetic theory, the emissivity of the insulator materials decreases sharply when the emission angle exceeds 60 degrees. From the experimental results, it was confirmed that the angle dependence in spectral emissivity obeys the above theory. Furthermore, it was clear that the spectral emissivity of the ceramic tiles in the middle infrared range was high when compared with the near infrared range and the far infrared range.

It is necessary to establish the IR thermography method to reduce the influence of IR reflection, which is important problem in non-destructive inspection using IR thermography.

9485-9, Session 2

Study of experimental parameters for IRT applications in building elements using multi-layered analytical solutions

Catarina L. Serra, ITeCons (Portugal) and Pólo II da Univ. de Coimbra (Portugal); Nuno A. Simões, Pólo II da Univ. de Coimbra (Portugal); António Tadeu, Univ. de Coimbra (Portugal)

This paper compares experimental and heat transfer modeling results for

thermography applications in building elements. Over the years, most building envelope inspections using infrared thermography (IRT) have been focused on qualitative analysis using mostly passive thermography techniques. However, increased need for the monitorization and the assessment of the energy performance and thermal behavior of buildings, along with ongoing structural safety concerns, has raised interest in quantitative studies and active IRT applications in buildings. Numerous other fields have benefited from developments in defect detection studies and from countless non-destructive testing applications. Pulse phase thermography, in which phase images are studied (instead of temperature images) using a long heating pulse has been suggested to be the most effective for Civil Engineering applications. Nonetheless, the particular characteristics of building elements and materials, along with the complex nature of heat transfer phenomena, demand specific experimental procedures and thermographic data processing techniques. In this paper, analytical solutions and numerical methods (Boundary Elements Method and Traction Boundary Elements Method) are used to simulate heat transfer in the frequency domain in media with embedded defects and in multi-layered media and compute thermal wave phase results. These results are compared to experimental IRT phase analysis results of experiments performed on test specimens simulating building elements. Crucial test parameters such as heating time and defect characteristics are changed, and their influence is studied. In this way, this paper contributes to the understanding of building envelope thermal patterns using active IRT in defect detection studies and to the definition of test parameters.

9485-10, Session 2

Active infrared thermographic testing with distance heating

Nagahisa Ogasawara, Hikaru Ando, Chie Kobayashi, Hiroyuki Yamada, National Defense Academy (Japan)

In order to efficiently inspect very wide area of concrete structure wall, an infrared thermographic testing with a distance heating was developed in this study. The researched subjects were the following three; 1. Improvement of radiant heating efficiency, 2. Development of distance heating method and 3. Development of data analysis method against non-uniformity of a heating and/or a wall absorptivity. According to investigation about combinations between the spectral emissivity of radiant heater and the spectral absorptivity of concrete, both a blackbody type and a far infrared type, e.g. a ceramics heater and a black coated heater, can heat a concrete wall more efficiently than a near infrared type, e.g. a halogen lamp heater and a xenon lamp heater. This is because the spectral absorptivity of concrete is higher in a far infrared region than in a near infrared region. In addition, a simple numerical simulation showed that the ideal heater, which can heat a concrete structure efficiently, should have a spectral emissivity that is almost zero in near infrared region. As a result of consideration of the spectral transmissivity of infrared lens, the lens made of sulfuration Zinc can transmit a radiant energy the most efficiently. However a lost energy by the lens absorption is not small, because the radiant energy from halogen lamp distributes in wide range of wave length. The pulse phase thermography was applied to data analysis, and the proposed system could identify experimentally the flaw part from irregular heated concrete specimen.

9485-11, Session 3

Comparison of lock-in and pulse-phase thermography for defect characterization in FRP composites applied to concrete

Jeff R. Brown, Sai Harsha Chittineni, Embry-Riddle Aeronautical Univ. (United States)

Thermal imaging is a well-established technique for the non-destructive evaluation of FRP composites applied to concrete. Defect characterization using IR thermograhy, however, remains a topic of on-going research, and there are currently no universally accepted standards for data collection or interpretation. This research involved the IR thermography inspection of two full-scale FRP strengthened bridge girders that were removed from service after approximately 15 years in a potentially corrosive marine environment. Trial inspections were first performed on test areas where defects could be identified using sounding methods. Two procedures showed the most promise for identifying and characterizing defects: sinusoidal (lock-in style) heating with periods ranging from 5 s to 40 s and constant step heating for 30 s followed by 70 s of cooling. Both methods resulted in a series of phase images that could provide insight into the depth and general nature of detected defects (e.g. air gaps vs. excess epoxy). This paper presents the findings of a comparison study between these two thermal imaging techniques and offers recommendations for standardizing data collection procedures during field inspections.

9485-12, Session 3

Crack depth determination with inductive thermography

Beata Oswald-Tranta, Roland Schmidt, Montan Univ. Leoben (Austria)

Castings, forgings and other steel products are nowadays usually tested with magnetic particle inspection, in order to detect surface cracks. An alternative method is active thermography with inductive heating, which is quicker, it can be well automated and as in this paper presented, even the depth of a crack can be determined. The induced eddy current, due to its very small penetration depth in ferro-magnetic materials, flows around a surface crack, heating this selectively. The surface temperature is recorded during and after the short inductive heating pulse with an infrared camera. Using Fourier transformation the whole IR image sequence is evaluated and the phase image is processed to detect surface cracks. The level and the local distribution of the phase around a crack correspond to its depth. Analytical calculations and finite element simulations were used to model the signal distribution around cracks with different depth and a relationship has been derived between the depth of a crack and its phase value. Additionally, also the influence of the heating pulse duration has been investigated. Samples with artificial and with natural cracks have been tested and the derived relationship has been used to determine the crack depth from measured data. Results are presented comparing the determined crack depth with the real depth values, obtained by metallographic cross-sections.

9485-13, Session 3

Measurement of flaw size from thermographic data

William P. Winfree, Joseph N. Zalameda, Patricia A. Howell, NASA Langley Research Ctr. (United States)

Simple methods for reducing the pulsed thermographic responses of delaminations tend to overestimate the size of the delamination, since the heat diffuses in the plane parallel to the surface. The result is a temperature profile over the flaw which is larger than the flaw size. A variational approach is presented for reducing the thermographic data to produce an estimated size for a flaw that is much closer to the true size of the delamination. The method is based on an estimate for the thermal response that is a convolution of a Gaussian kernel with the shape of the flaw. The size is determined from both the temporal and spatial thermal response of the exterior surface above the delamination and constraints on the length of the contour surrounding the delamination. Examples of the application of the technique to simulation and experimental data are presented to investigate the limitations of the technique.

9485-14, Session 3

Characterization of vertical cracks using ultrasound excited lock-in thermography

Arantza Mendioroz, Univ. del País Vasco (Spain); Ricardo Celorrio, Univ. de Zaragoza (Spain); Agustín Salazar, Univ. del País Vasco (Spain)

We present a method that combines (ultra)sonic-infrared experiments in the lock-in regime and inverse methods to characterize vertical cracks. We present an analytical model to calculate the surface temperature distribution corresponding to vertical cracks of different shapes and we develop inverse methods to retrieve the shape, size and location of the crack from surface temperature data. Since this inverse problem is ill-posed, we have developed stabilized inversion algorithms to obtain an accurate characterization of the crack by combining lock-in thermography data obtained at several modulation frequencies, between 0.05 and 13 Hz. First, by inverting synthetic data with added white noise, we analyze the maximum depth of a square crack for the method to give an accurate reconstruction. Moreover, we analyze the capability of the method to resolve two square cracks as a function of their depth. The predictions of the reconstructions from synthetic data are checked by performing lock-in vibrothermography experiments on samples containing calibrated simulated cracks. In order for the sample to reach the steady state quickly and also to prevent it from being damaged or altered, data are obtained at low (below 50 W) ultrasound power. In these conditions, the signal-to-noise-ratio is improved by using the lock-in method in which we analyze a high number of images. The inversions obtained from experimental data validate the results obtained from synthetic data. The results are very promising regarding the characterization of real vertical cracks.

9485-15, Session 3

Automatic thermographic scanning with the creation of 3D panoramic views

Alessandro Bortolin, Gianluca Cadelano, Giovanni Ferrarini, Consiglio Nazionale delle Ricerche (Italy)

Infrared thermography is widely applied to the inspection of building, enabling the individuation of thermal anomalies due to the presence of hidden structures, air leakages, and moisture. One of the main advantages of this technique is the possibility to acquire rapidly a temperature map of a surface. However, due to the actual low-resolution of thermal camera, during a building survey it is necessary to take multiple images in order to scan all the surfaces.

In this work a device based on quantitative infrared thermography, called aIRview, has been applied during building surveys to automatically acquire thermograms with a camera mounted on a robotized pan tilt unit. The goal is to perform a first rapid survey of the building that could give useful information for the successive quantitative thermal investigations For each data acquisition, the instrument covered a rotational field of view of 330° around the vertical axis and of 210° around the horizontal one. The obtained images have been processed in order to create an equirectangular projection of the ambient.

For this reason the images have been integrated into a web visualization tool, working with flash-based software or with the Google Street View algorithms, creating a webpage where it is possible to have a three dimensional virtual visit of the building. The thermographic data are embedded with the visual imaging and with other sensor data, facilitating the understanding of the physical phenomena underlying the temperature distribution.

9485-16, Session 3

Comparison of step heating and modulated frequency thermography for detecting bubble defects in colored acrylic glass

Hongjin Wang, Sheng-Jen Hsieh, Texas A&M Univ. (United States)

Bubble defects are a cause for recall and rejection of glass materials and products in industry. Often these defects are difficult to see, particularly if they are small or if they are located below the surface of the glass. This study compared active step heating thermography (SHT) and modulated frequency thermography (MFT) for effectiveness in detecting bubble defects in samples of colored acrylic glass. The defects ranged in size from 1.98 mm to 6 mm in diameter and were located at various depths ranging from 1.5 mm to 4 mm below the surface of the sample. After a series of experiments, we found that SHT can be used to detect shallow defects as early as 4 seconds after heating. When heating time is lengthened, defects of 4 to 6 mm in diameter buried 1.5 mm to 4 mm below the surface can be detected. In contrast, MFT provided a higher signal to noise ratio of 1.3 and could be used to detect defects as small as 1.98 mm in diameter at depths of up to 4 mm beneath the glass surface. Obtaining these results required reducing phase frequency by an order of 10^-3. Future directions include development of a systematic method and/or rule of thumb for determining the appropriate frequency for different defect types.

9485-17, Session 3

Detection of pinhole defects in optical film using thermography and artificial neural network

Hongjin Wang, Texas A&M Univ (United States); Sheng-Jen Hsieh, Bhavana Singh, Texas A&M Univ. (United States)

As the use of optical film for liquid crystal display applications has increased in recent years, it has become challenging to mass produce quality film. Micro defects in the film can lead to display failure. Optical and visual methods for detecting defects have had little success due to the reflective nature of the film and to difficulty in setting up illumination sources and establishing appropriate viewing angles. This study developed an artificial neural network model for detecting pinhole defects in film. Nine defect sizes ranging from 0.03mm to 4 mm in diameter were investigated. The thermal response of the film during heating and cooling was captured using an infrared camera. An artificial neural network (ANN) model was trained to detect the presence of the pinhole defects. Temperature variation, average absolute temperature difference, and cooling rate were used as input nodes for the model. Two-thirds of the data set was used for training and one-third was used for model verification. The model was able to classify samples as defective or non-defective with 81% accuracy. The residual between the predicted value and the output was 12%. Future directions include mathematical model development for estimating and classifying defect sizes and types.

9485-18, Session 3

Testing and evaluation of concrete structures by thermal wave imaging

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Reinforced concrete structures (RCS) have budding application in civil engineering due to their high strength, durability, sustainability, flexibility in making complex shapes. However, loss of durability of constructed structures due to premature corrosion of rebar is a major constraint. An initial stage of cracking in concrete is not detectable by visual inspections. With a view to avoid catastrophic failure and massive repair of structures, it is essential to determine damage at low levels. Growing concernment about safety of the structure due to premature deterioration has led to a significant demand for advancement of non-destructive testing and evaluation (NDT&E) techniques for monitoring and assessing health of RCS. This paper highlights a whole-filed, remote, non-destructive testing and evaluation method based on infrared thermography for identifying hidden corrosion of rebar in a concrete structure. Results shown for both time and frequency domain transform techniques proves the effectiveness of the proposed approach for identification of corrosion in rebar in the concrete samples.

9485-19, Session 3

Studying industrial-scale rack-storage fires using IR thermography

Jaap de Vries, FM Global (United States)

There is continued interest in the development of fire modeling tools having predictive abilities regarding large-scale fire phenomena. To this end, FM Global has recently developed an open-source CFD fire simulation code, FireFOAM. Such codes heavily rely on experimental data, obtained at various scales, for validation. However, at larger scales, detailed measurements of local quantities (e.g., surface temperature) needed for model validation become increasingly complex. Therefore, often times, data for large-scale fires are simply limited to global heat release rates. The present study addresses this limitation by introducing IR thermographic measurements in large-scale scenarios relevant to industrial warehouse fires.

Experiments were carried out under a 20-MW calorimeter in FM Global's Fire Technology Laboratory on three- and five-tier-high rack-storage arrays. The commodities considered consisted of three nested double-wall corrugated cardboard boxes surrounding a metal liner and resting on a hardwood pallet. This type of fuel represents a simple yet realistic industrial commodity. An in-house calibrated microbolometer IR camera was used to obtain temporal and two-dimensional temperature measurements on fuel surfaces, which were compared with far-field radiometer results. Maximum temperatures up to 1050ºC were observed on the external surfaces of the test array. Inside the flue spaces between pallet loads, temperatures up to 1250ºC were measured. Timing of the peak radiance measured using the IR camera and peak heat release rate measurements from the calorimeter were compared. These temperatures are higher than those obtained through CFD modeling, which can be attributed to the effect of char oxidation.

The present study demonstrates the value of IR thermography applied to large-scale fires. The availability of surface temperature data in such scenarios provides fundamental insights into the mechanisms of fire spread and radiation phenomena that can be used to evaluate the results of fire simulations.

9485-20, Session 4

Advances in infrared fibers *(Invited Paper)*

Guangming Tao, Ayman F. Abouraddy, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Infrared fibers offer a versatile approach to guiding and manipulating light in the infrared spectrum, which is becoming increasingly more prominent in a variety of scientific disciplines and technological applications. Despite well-established efforts on the fabrication of infrared fibers over the past decades, a number of remarkable breakthroughs have recently rejuvenated the field – just as related areas in infrared optical technology are reaching maturation. In this review, we describe both the history and recent developments in the design and fabrication of infrared fibers including infrared glass and single-crystal fibers, multimaterial fibers, and fibers that exploit the transparency window of traditional crystalline semiconductors. This interdisciplinary review will be of interest to researchers in optics and photonics, materials science, and electrical engineering.

9485-21, Session 4

Logarithmic InGaAs detectors with global shutter and active dark current reduction

Yang Ni, New Imaging Technologies (France)

In this paper, we present newly developed logarithmic InGaAs detectors with global shuttering and also an active dark current reduction technique to insure ambient temperature operation without TEC for industrial applications. The newly released detectors come with both VGA (15um pitch) and QVGA (25um pitch) resolutions, giving the possibility to use lens less than 1-inch size. The logarithmic response is obtained by using solar-cell mode InGaAs photodiodes.

The VGA and QVGA ROICs have 3 analog memories inside each pixel which permit, except the classic ITR, IWR and CDS modes, a new differential imaging mode which can be a useful feature in active imaging systems. The photodiode front-end circuit, in pure voltage mode, is made with non-inverting amplifier instead of CTIA. The reason of this choice is that the exposure time can be shortened without need of excessive power consumption as in CTIA front-end. We think that this arrangement associated true CDS could match the noise performance of CTIA based one.

Both ROIC have been designed and manufactured by using 0.18um 1P4M CMOS process. Both ROIC have been tested with success and match the design targets. The first batch of both detectors is under fabrication and will be presented during the conference.

9485-22, Session 4

The fabrication of sub-micron size caesium iodide x-ray scintillator

Chien Wan Hun, Po Chun Chen, National United Univ. (Taiwan); Ker Jer Huang, Chung-Shan Institute of Science and Technology (Taiwan); Chien-Chon Chen, National United Univ. (Taiwan)

The caesium iodide (CsI) scintillator can converts incident X-ray into visible light with very high conversion efficiency of optical photons. The incident energy, response time, film thickness, sample size, and spatial resolution requires in engineering and medical applications are difference. A smooth and flat surface and single crystal structure of CsI enhance the X-ray to visible light conversion. However, the regular CsI is soft and extremely hygroscopic; it is very difficult to polish to obtain a smooth and optical flat plane. In order to obtain a good quality of CsI scintillator for X-ray application we used an ordering channel as template and formed sub-micron CsI wire in the template. The fabrication process including: (1) Ordering structure of nano or sub-micron channels were made by an anodization method; (2) fill CsI scintillated film on the channel by CsI solution, (3) fill CsI melt into the channel formation single crystal of sub-micron crystalline scintillator after solidification. The non-vacuum processes of anodization and solidication methods were used for the sub-micron CsI scintillator column formation that is cost down the scintillator fabrication. In addition, through the fabrication method, the ordering structure scintillator of scintillator can be made by anodic treatment and die casting technology with low cost and rapid production; moreover, the film oxidized metal tubes of the tubular template can be further manufactured to nano tubes by adjusting electrolyte composition, electrolysis voltage, and processing time of anodic treatment, and the aperture size, the thickness and the vessel density of the nano tube can be controlled and ranged from 10 nm to 500 nm, 0.1 ?m to 1000 ?m, and hundred million to thousand billion tube/cm2, respectively.

9485-23, Session 4

Swap intensified WDR CMOS module for I2/LWIR fusion

Yang Ni, New Imaging Technologies (France)

In this paper, we present a SWAP intensified Wide Dynamic Range CMOS module for night vision applications, especially for I2/LWIR fusion. This module is based on a dedicated CMOS image sensor using solar-cell mode photodiode logarithmic pixel design which covers a huge dynamic range (> 140dB) without saturation and blooming. The format of this CMOS sensor has been tailed to match the whole surface of standard 18mm II tube with 1280x1024 pixels of 10.6um pitch. The incorporated scanning modes include full resolution and central x2 zoom/2x2 binning to VGA resolution, creating instant narrow and wide field of view switching.

We will present also the special optimization applied on the CMOS process level in order to improve the MTF in fiber optic coupling process with II tube. 50lp/mm limit resolution has been obtained with XR5 grade II tube. The final module has very compact size with 1/4 watt consumption and capability to deliver 50 images per second at full resolution. The huge dynamic range and blooming-less operation of this sensor extracts the full performance of II tube under all night light conditions and improves considerably the performance of an NIR-VIS/LWIR fused vision system on the real operation theatre.

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9485-24, Session 4

Highly sensitive arrayed indium-antimony nanowires for infrared detection

Po-Chun Chen, National Chiao Tung Univ. (Taiwan); Chien-Chon Chen, National United Univ. (Taiwan); Shih-Hsun Chen, National Chiao Tung Univ. (Taiwan); Chung-Yi Chou, National United Univ. (Taiwan); Sheng-Jen Hsieh, Texas A&M Univ. (United States)

The objective of this study is to achieve a high sensitive infrared detector by fabricating highly ordered array of indium-antimony (In-Sb) nanowires which is a semiconductor material. The approach is to investigate an infrared detector with arrayed nanowires which can transport signals in one dimension to obtain high efficiency and sensitivity compared with In-Sb by using traditional thin film fabrications. This research expects to provide an infrared detector by fabricating III-V alloy nanowires to highly improve the resolution of infrared signal. To develop scaled-up functional devices, highly ordered nanowire arrays are essential building blocks. Many candidate materials (metals, alloys, oxides and semiconductors) have been studied for various potential applications in nanotechnology and have shown some promising results. The solid metallic nanowires have been exploited for a wide range of applications to take the advantages of their large length/diameter aspect ratio. Further development to synthesize nanowires efficiently at lower cost is the direction for manufacturing next generation nanodevices. In this study, various diameters of ordering nanowires, from 10 nm to 500 nm, were fabricated and evaluated the performance of the sensitivity of infrared detection. Moreover, a 1 inch plate, which can be regarded as a device, with nanowires array was fabricated by designing a new type of processing chamber.

9485-25, Session 4

Computational methods for improving thermal imaging for consumer devices

Colm N. Lynch, National Univ. of Ireland, Galway (Ireland) and Tessera (FotoNation) Ireland Ltd. (Ireland); Nicholas Devaney, National Univ. of Ireland, Galway (Ireland); Alexandru Drimbarean, Tessera (FotoNation) Ireland Ltd. (Ireland)

In recent years, uncooled microbolometer arrays have increased in popularity, while there has also been a decrease in sensor footprint. Adoption of such sensors in consumer imaging is likely in the near future, as is evidenced by the recent release of a number of consumer-level smartphone imaging accessories built around thermal cores; among them the FLIR One attachment. Due to the relatively large size of the Airy disc across thermal wavelengths and the limited size allowances of mobile phone packaging, the maximum output resolution of entry-level thermal sensors is unlikely to increase dramatically without major innovation in camera phone manufacturing. As consumers are accustomed to megapixel resolutions, this problem must be addressed. We propose a purely computational method to increase the output resolution of such sensors, incorporating both sub-pixel shifts and temporal variations in the scene. A resolution increase is possible provided that the maximum spatial resolution of the system is limited by the pixels. In addition to these methods, a dual IR-visible camera system was custom built to fully simulate a range of use cases. Supplemental information from the visible spectrum is incorporated in the super-resolution scheme, providing precise shift values and structural information that is not present in the thermal channel. Special consideration is given to retaining temporal information from thermal images in a super-resolved output, from which further thermal structural detail is inferred through a specialized extension of Eulerian Video Magnification. Simulations of the super-resolution method are described and results from the experimental imaging setup are presented.

9485-26, Session 5

Pulsed thermal NDT in tables, figures and formulas *(Invited Paper)*

Vladimir P. Vavilov, Tomsk Polytechnic Univ. (Russian Federation); Douglas Burleigh, Surf Consulting (United States)

Pulsed thermal nondestructive testing (TNDT) is being increasingly used in the inspection of composite materials. The theoretical basis of this technique has been successfully developed in recent decades. This included both direct solutions for heat conduction problems (modeling) and inverse solutions (defect characterization). The practical implementation of pulsed TNDT hardware is also becoming more widely used due to the availability of infrared (IR) thermographic modules which allow the development of portable inspection units for both laboratory and field conditions.

Several reviews and summary papers describing the history and the current status of pulsed TNDT have been published recently. However, some publications were not impartial or objective. In addition, some of the theoretical possibilities cannot easily be implemented in practical applications.

This paper contains useful tables and formulas that are illustrated with typical IR thermograms to provide a general overlook of pulsed TNDT.

Hopefully this review will be valuable to experienced TNDT practitioners as well as to beginners in the field.

9485-27, Session 5

Advances in thermographic signal reconstruction *(Invited Paper)*

Steven M. Shepard, Thermal Wave Imaging, Inc. (United States)

Since its introduction in 2001, the Thermographic Signal Reconstruction (TSR) method has been the subject of numerous investigations and comparative studies. It has emerged as one of the most widely used methods for enhancement and analysis of thermographic sequences, with applications extending beyond industrial NDT into biomedical research, art restoration and botany. The basic TSR process, in which a noise reduced replica of each pixel time history is created, yields improvement over unprocessed image data that is sufficient for many applications. However, examination of the resulting logarithmic time derivatives of each TSR pixel replica have facilitated significant insight into the details of the active thermography process. The deterministic and invariant properties of the derivatives has facilitated the successful implementation of automated defect recognition and measurement systems. Unlike most approaches to analysis of thermography data, TSR does not depend on flaw-background contrast, so that it can be applied to characterization and measurement of thermal properties of flaw-free samples. We present a summary of recent advances in TSR, a review of the underlying theory and examples of its implementation.

9485-28, Session 5

Principal component analysis of thermographic data *(Invited Paper)*

William P. Winfree, K. Elliott Cramer, Joseph N. Zalameda, Patricia A. Howell, Eric R. Burke, NASA Langley Research Ctr. (United States)

Principal Component Analysis (PCA) has been shown effective for reducing thermographic NDE data. While a reliable technique for enhancing the visibility of defects in thermal data, PCA can be computationally intense and time consuming when applied to the large data sets typical in thermography. Additionally, PCA can experience problems when very large defects are present (defects that dominate the field-of-view), since the calculation of the eigenvectors is now governed by the presence of the defect, not the “good” material. To increase the processing speed and to minimize the negative effects of large defects, an alternative method of PCA is being pursued where a fixed set of eigenvectors, generated from either acquired data or a simulation of the thermal response of the material under examination, is used to process the thermal data from the material. Details of a one-dimensional analytic model and a two-dimensional finite-element model will be presented. An overview of the PCA process as well as a quantitative signal-to-noise comparison of the results by performing both embodiments of PCA on thermographic data from specimens will be shown. Finally, a number of different applications of this technology for characterization of flaws will be presented.

9485-29, Session 5

Review of pulse phase thermography *(Invited Paper)*

Clemente Ibarra-Castanedo, P. Servais, Xavier Maldague, Univ. Laval (Canada)

In this paper, Pulse Phase Thermography (PPT) will be reviewed in the context of NDT. It is recalled PPT was proposed in 1996 as a new mean to look at thermographic data obtained from pulsed experiments. Up to that time, two stimulation approaches were common for thermographic NDT. Pulsed thermography (PT) which consists in flash-heating specimens and lockin thermography (LT) which consists in modulated heating. In PT, images were generally processed in the time domain by mean of a contrast. Such temperature differences observed on the specimen surface corresponds to how well or not the heat flow propagates within the bulk of the specimen. A subsurface defect acts as a thermal barrier, hence the «heat accumulates» just over it translating as a higher surface temperature. In LT, the images were processed in the phase domain. Phase is related to the propagation delay of the thermal waves propagating into the specimens. A careful choice of the stimulation modulated frequency yields to thermal waves propagating at the depth corresponding to possible defects (for example the glue line in a laminate).

By analyzing the PT data in the frequency domain thanks to the Fourier transform, PPT enabled PT data to be analyzed as LT data and thus unified somehow these two approaches. Moreover, such analysis enhanced significantly the results by reducing the noise (optical heating and infrared effects).

Since then, PPT has been adopted by the community and is a common tool nowadays.

In this paper, PPT will be presented and its capabilities will be demonstrated on various specimens.

9485-30, Session 5

Development of self-reference lock-in thermography and its applications to nondestructive testing *(Invited Paper)*

Takahide Sakagami, Kobe Univ. (Japan)

Self-reference lock-in data processing technique was developed for the improvement of signal-to-noise ratio of the thermal images obtained by infrared thermography. In this paper, experimental results of nondestructive testing by the self-reference lock-in thermography are shown compared with other thermal data processing technique.

9485-31, Session 5

A novel data processing algorithm in thermal property measurement and defect detection by using one-sided active infrared thermography

Vladimir P. Vavilov, Tomsk Polytechnic Univ. (Russian Federation)

Comparison between one- and two-sided test procedures is an ongoing issue in thermal nondestructive testing (NDT). From the theoretical point of view, two-sided procedures seem to be more appropriate to provide a more accurate measurement of thermal properties, as well as a more reliable detection of defects arbitrarily located throughout a test specimen. A good illustration to this statement is the known Parker method intended for determining thermal diffusivity. Basically, this is a two-sided pulsed technique which takes into account material properties averaged by sample thickness. The same statement adheres to thermal NDT of hidden defects. The difficulty in using a one-sided procedure is that it does not provide some evident specific points in the front-surface temperature evolution which can be used for reliable data inversion. In practice, another drawback of one-sided procedures is the presence of reflected radiation produced by a heat source that is used for stimulation.

The new algorithm recently proposed at National Research Tomsk Polytechnic University is based on the analysis of an artificial function which includes temperature and time. This function experiences certain extremums (typically-minimums), and the corresponding observation times can be used for determining thermal diffusivity by the formula similar to the Parker one. In thermal NDT, such approach being applied to defect areas, provides diffusivity variations which can be used for the evaluation of defect severity in a particular specimen. In this study, both the theoretical basis and

the some experimental implementations of the proposed data processing algorithm have been explored to prove its principle validity in thermal properties measurement and thermal NDT, including thermal tomography.

9485-32, Session 5

Signal and image processing techniques for testing and evaluation of glass fibre reinforced polymers

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Glass Fibre Reinforced polymer (GFRP) composites are being used in a wide range of application areas since these materials are less affected by corrosive environmental conditions and provide longer life with less maintenance. However, there are still some concerns about reinforced polymers, such as the presence of surface and sub-surface defects which effects their in service applications. To detect these defects, InfraRed Thermographic (IRT) methods shows their potential usage for non-destructive testing and evaluation (NDT&E) of composite materials due to its inherent testing capabilities such as remote, whole field, quantitative and qualitative to detect surface and sub-surface defects. Thermal NDT&E is broadly categorized into passive or active approach. In passive approach the test sample's temperature distribution will be monitored in the absence of any external heat stimulus at ambient conditions. However, this may not provide ample thermal contrast to detect the defects located at deeper depths. In order to detect deeper defects inside the test specimen an active thermography is preferred. This can be carried out by applying an external heat stimulus, to induce enough thermal contrasts over the test object. The thermal gradient appear over the material during the active heating due to the changes in thermal properties of defective and sound region leads to detect the subsurface defects. This present work highlights a spectral reshaping by introducing a Gaussian window on the captured thermal profile in a frequency modulated thermal wave imaging and named as Gaussian windowed frequency modulated thermal wave imaging (GWFMTWI) technique. Further various multi-transform techniques (time and frequency domain based) have been introduced in order to test sub-surface defect detection capabilities in chosen GFRP sample. Comparison has been made with the non-stationary linear frequency modulated thermal wave imaging technique in terms of depth scanning capability. Results obtained from the GWFMTWI clearly shows better detection potential with improved test resolution and sensitivity.

9485-33, Session 6

Infrared thermography, ultrasound C-scan and microscope for non-destructive and destructive evaluation of 3D carbon fiber materials: a comparative study

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Thick 3D Carbon fiber polymer matrix composites (3D CF PMCs) are increasingly used for aircraft construction due to their exceptional stiffness- and strength-to-mass ratios. Defects are much more common in the 3D combining areas. However, 3D non-destructive infrared thermography (IR NDT) is poorly documented currently. In this paper, IR NDT is used to inspect 3D carbon fiber samples. In particular, a non-contact laser lock-in thermography technique (LLT) is used to detect and evaluate the defects in 3D carbon fiber samples. LLT utilizes a modulated continuous wave laser as a heating source for lock-in thermography instead of the usual flash and halogen lamps. For comparison purposes, conventional flash and halogen lamps are used to detect the defects in 3D samples as well.

In addition, both optical pulsed thermography (PT) and mechanical vibrothermography (VT) are also used to inspect the same samples. Different image processing methods are used depending on the different experimental methods used. Finally a comparative study is conducted for LT, PT and VT.

An ultrasound C-scan non-destructive test (UT NDT) is also conducted to inspect the same samples. The results from UT NDT are compared to the corresponding IR NDT results. Advantages and disadvantages of IR NDT and UT NDT are clearly identified according to these comparisons.

In order to verify these defects detected using IR NDT and UT NDT, a microscope inspection after cutting and polishing the samples is carried out. A comparison between NDT and DT is also conducted thereafter.

Experimental results show that IR and UT have respective advantages depending on different defects.

9485-34, Session 6

Characterization of phononic heterostructures by infrared thermography

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This work deals with the development of a new class of metamaterials based on phononic composite structures that can offer vibration protection in a wide range of applications. Such phononic heterostructures is a class of phononic crystals that exhibit spectral gaps with lattice constants of a few orders of magnitude smaller than the relevant acoustic wavelength. The design of a phononic composite metamaterial is based on the formation of omnidirectional frequency gaps. This is very much relevant to the dimensionality of a finite slab of the crystal. In this respect, two dimensional structures are used to cut off acoustic waves. In this study, different infrared thermography techniques were used in order to assess the phononic structure's geometry, as well as to determine the thermal properties of the metamaterial.

9485-35, Session 6

Superimpose methods for uncooled infrared camera applied to the micro-scal thermal characterization of composite materials

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The mobile type apparatus for a quantitative microscale thermography using a micro-bolometer was developed based on our original techniques such as an achromatic lens design to capture a micro-scale image in long-wave infrared, a video signal superimposing for the real time emissivity correction, and a pseudo acceleration of a timeframe. The total size of the instrument was designed as it was put in the 17 cm x 28 cm x 26 cm size carrying box.

The video signal synthesizer enabled to record a direct digital signal of monitoring temperature or positioning data. The encoded digital signal data embedded in each image was decoded to read out. The protocol to encode/decode the measured data was originally defined. The mixed signals of IR camera and the imposed data were applied to the pixel by pixel emissivity corrections and the pseudo-acceleration of the periodical thermal

phenomena. Because the emissivity of industrial materials and biological tissues were usually inhomogeneous, it has the different temperature dependence on each pixel. The time-scale resolution for the periodic thermal event was improved with the algorithm for "pseudo-acceleration". It contributes to reduce the noise by integrating the multiple image data, keeping a time resolution.

The anisotropic thermal properties of some composite materials such as thermal insulating materials of cellular plastics and the biometric composite materials were analyzed using these techniques.

9485-36, Session 6

A numerical approach for testing and evaluation of mild steel material by thermal wave imaging

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Among several commonly used infrared non-destructive testing and evaluation methods, non-stationary thermal non-destructive testing modalities have proved to be an imperative approach for the inspection and evaluation of various solid materials. These techniques makes use of relatively low peak power heat sources in a moderate time compared with the conventional pulsed thermography and sinusoidal modulated (lock-in) thermography approach respectively. This present work introduces a novel 11-bit Barker coded thermal wave imaging approach for characterization of mild steel sample having flat bottom holes as defects. Capabilities of the proposed approach has been studied on a mild steel sample containing flat bottom holes as sub-surface defects located at different depths modeled using a finite element method. Results show the depth detection capabilities of the proposed 11-bit Barker coded excitation scheme as a promising testing and evaluation method to detect the subsurface defects.

9485-37, Session 6

Characterization of nuclear graphite elastic properties using laser ultrasonic methods

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Laser ultrasonic methods have been used to characterize the elastic behaviors of commercially-available and legacy nuclear graphites. Since ultrasonic techniques are sensitive to various aspects of graphite microstructure including preferred grain orientation, microcrack orientation and porosity, laser ultrasonics is a candidate technique for monitoring graphite degradation and structural integrity in environments expected in high-temperature, gas-cooled nuclear reactors. Aspects of materials texture can be assessed by studying ultrasonic wavespeeds as a function of propagation direction and polarization. Shear wave birefringence measurements, in particular, can be used to evaluate elastic anisotropy. In this work, laser ultrasonic measurements of graphite moduli have been made to provide insight into the relationship between the microstructures and the macroscopic stiffnesses of these materials. In particular, laser ultrasonic measurements have been made using laser line sources to produce shear waves with specific polarizations. By varying the line orientation relative to the sample, shear wave birefringence measurements have been recorded. Results from the shear wave birefringence measurements show that an isostatically molded graphite, such as IG-110, behaves isotropiclly, while an extruded graphite, such as PCEA, displays significant ultrasonic texture. Graphites have complicated microstructures that depend on the manufacturing processes used, and ultrasonic texture in these materials could originate from grain orientation and also from preferred microcrack alignment. Changes to material isotropy due to service related microstructural changes are possible and the ultimate aim of this work is to determine the degree to which these changes can be assessed nondestructively using laser ultrasonics measurements.

9485-46, Session 6

Thermal diffusivity estimation with quantitative pulsed phase thermography

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Pulsed Phase Thermography (PPT) transforms the pulsed thermography sequence in time domain into the frequency domain using discrete Fourier transform. This transformation is performed for each pixel. Phase data is less affected by local surface optical variations and so it is reported to detect defect approximately twice the depth of the temperature data. Another important advantage of PPT is that the phase angle, is generally not sensitive to undesirable conditions in pulsed thermography such as non-uniform heating or surface emissivity variation.

PPT also permits quantitative analysis by estimating the depth of delaminations or flat bottom holes in composite samples. In one approach, the flaw depth is evaluated from the relationship between the relative phase angle (phase contrast between defect and non-defective area) and length ratio (delamination depth/diffusion length). Another type of depth quantification with PPT defines a model based on thermal quadrupole theory to attain an analytical expression of phase contrast in Laplace domain where defect depth and thermal resistance appear explicitly.

In practice, quantitative PPT has been only used to estimate defect parameters such as depth and thermal resistance. An approach to estimate thermophysical properties, such as thermal diffusivity, through PPT had not been introduced until the quantitative PPT method discussed in this work. Here, we propose a thermal quadrupole based method that extends quantitative pulsed phase thermography. This approach estimates thermal diffusivity by solving an inversion problem based on non-linear squares estimation.

This approach is tested with pulsed thermography data acquired from a composite sample whose configuration. The estimation algorithm calculates thermal diffusivity for each pixel (i,j) in the image to generate a thermal diffusivity map. We compare our results with other techniques established in time domain. The proposed quantitative analysis with PPT provides low error estimations of thermal diffusivity. This estimation requires only the a priori knowledge of sample thickness.

9485-38, Session 7

IR-based spot weld NDT in automotive applications

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Today's auto industry primarily relies on destructive teardown evaluation to ensure the quality of the spot welds due to their criticality in crash resistance and performance of vehicles. The destructive teardown evaluation is labor intensive and costly. The very nature of the destructive test means only a few selected welds will be sampled for quality. Most of the welds in a car are never checked. There are significant costs and risks associated with reworking and scrapping the defective welded parts made between the teardown tests.

IR thermography as a non-destructive testing (NDT) tool has its distinct advantage — its non-intrusive and non-contact nature. This makes the IR based NDT especially attractive for the highly automated assembly lines. IR for weld quality inspection has been explored in the past, mostly limited to the offline post-processing manner in a laboratory environment. No online real-time RSW inspection using IR thermography has been reported. Typically for post-processing inspection, a short-pulse heating via xenon flash lamp light (in a few milliseconds) is applied to the surface of a spot weld. However, applications in the auto industry have been unsuccessful, largely due to a critical drawback that cannot be implemented in the high-volume production line – the prerequisite of painting the weld surface to eliminate surface reflection and other environmental interference. This is due to the low signal-to-noise ratio resulting from the low/unknown surface emissivity and the very small temperature changes (typically on the order of 0.1°C) induced by the flash lamp method.

An integrated approach consisting of innovations in both data analysis algorithms and hardware apparatus that effectively solved the key technical barriers for IR NDT. The system can be used for both real-time (during welding) and post-processing inspections (after welds have been made). First, we developed a special IR thermal image processing method that utilizes the relative IR intensity change, so that the influence of surface reflection and environment interference can be reduced. Second, for the post-processing inspection, a special induction heater is used to replace the flash lamp, resulting in temperature changes on the order of 10°C. As a result, the signal-to-noise ratio increased by several orders of magnitudes with no surface painting needed, and the inspection results are more accurate and reliable. For real-time inspection, the heat from welding (with temperature exceeding 1000°C) was utilized. Third, “thermal signatures” were identified to uniquely correlate to different weld quality attributes through computational modeling of heat transfer and extensive testing of specially designed ranges of welding conditions. Novel IR image analysis algorithms that automatically and intelligently identify the “thermal signatures” from the IR images and positively determine the weld quality in less than a second were developed.

9485-39, Session 7

Laser beam welding quality monitoring system based in high-speed (10 kHz) uncooled MWIR imaging sensors

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Laser beam welding (LBW) is a welding technique used to join multiple pieces of metal through the use of a laser. The beam provides a concentrated and quite intense heat source, allowing for narrow, deep welds and high welding rates. The investment required to implement the process is very high, and therefore it is frequently used in high-volume applications. It has been the automotive industry the main driver to spread this welding technique in the production lines.

As it happens in the Resistance Spot Welding technique, where current flow meters and pressure sensors are used to monitor the process but not electro-optical sensors, there is a lack of an appropriate low-cost sensing technology to perform an in-line real-time monitoring of the LBW process. Some EO sensors are capable to monitor the penetration of the welding in real-time; however, the cost of these sensors makes unfeasible their implementation in every welding station. In addition, LBW process is quite dynamic, and therefore it requires sampling speeds of several kHz. The appearance of high-speed, uncooled imaging MWIR sensors made of VPD PbSe opens the possibility to perform such process monitoring at an affordable cost.

In order to demonstrate the capabilities of this technology, one of these sensors has been assembled to a production LBW machine, allowing a direct observation and real-time data acquisition of the Heat Affected Zone (HAZ) using frame rates of 2 kHz. Several welding processes have been recorded with the aim to study the performance of the infrared sensor and its application to the real-time monitoring of the process. During the experiments, some faults have been also introduced. This paper will review the experimental results obtained after the analysis of the data.

9485-40, Session 7

Comparison of the insulation property of an innovative material and a traditional one by infrared thermography

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An innovative ceramic material has been developed as a possible substitute of the traditional rockwool as thermal insulating material. It should be used in the future inside a machine working at a temperature greater than 200 °C. Several measurements have been carried out on this new material by means of Laser Flash technique and Differential Scanning Calorimeter to evaluate the thermal conductivity at 200 °C. The effect of exposition to this temperature for several hours has been evaluated as well, to check if a degradation of the insulating properties can be measured. Experiments did not show any evidence of degradation. Nonetheless the value of the thermal conductivity measured both at high and ambient temperature was not so good as expected. At the same time, the same measurements on rockwool (the traditional choice for insulation in this machinery) reavealed to be very difficult as it is not possible to prepare samples to be tested in a laser flash. To overcome this problem in the measurement of the performance at high temperature a new experiment was prepared by heating one side of the material by means of an electric heater and by looking and comparing (at least qualitatively) the temperature increase on the other side. On the purpose, two parallelepiped samples of the two rival materials, with the same thickness have been prepared and put in contact with the electric heater plate. The temperature of the heater has been controlled by a suitable Variac transformer. The temperature evolution of the side facing the ambient has been measured by means of a thermographic camera for almost one hour. An analytical model has been used to evaluate the expected behaviour of the material with boundary conditions that can be approximated to those of prescribed temperature on one side (the one in contact with the heater) and exchange with the environment on the other (the one facing the ambient and visible by the IR camera). The experiment shows that the traditional material owns better insulation performance than the innovative one. Attention has been paid on the properties of the innovative material that, being highly hygroscopic, can maintain a low temperature during the drying process due to the very high value of the latent heat of water when changing from liquid to gas phase. This can lead to wrong evaluation of the insulating properties by the comparison technique adopted.

9485-41, Session 7

Thermographic investigation of luminescent barium borate glasses for white-LED applications

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White light-emitting diodes (W-LEDs) represent one of the most promising lighting technologies for the future. Primarily used in many lighting applications is a blue LED in combination with a yellow phosphor. The phosphor powder is usually embedded in an organic polymer and directly coated onto the LED chip. This setup, however, is often subject to heat-induced degradation of the organic encapsulate resulting in an efficiency decrease and in a change of the color temperature. Luminescent glasses or glass ceramics are an interesting alternative to the above-mentioned phosphor / polymer combination; the organic encapsulate is no longer necessary. In addition, glasses and glass ceramics provide for a high thermal and chemical stability.

This work focuses on the thermal behavior of luminescent barium borate glasses and glass ceramics under intense laser beam excitation. The glasses and glass ceramics are doped with rare-earth ions for optical activation. Upon absorbing the incident laser beam the rare-earth ions show their typical emission in the visible spectral range. However, not all of the absorbed laser power is converted to light, but a significant part is released in the form of heat. Contact-free infrared thermography enables then for an analysis of the heat development in these materials. An algorithm based on solving the partial differential heat equation is developed to calculate the heat source density of the laser excitation from the surface temperature distribution. Time-resolved thermographic images are taken and used to validate the developed algorithm. There is good agreement between the calculated heat source density and the laser-induced heat power generated in the glass.

9485-42, Session 7

About infrared scanning of photovoltaic solar plant

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This paper is discussing about infrared scanning of PV solar plants. It is important that the performance of each solar panel and cell is verified. One new possibility compared to traditional ground-based scanning (handheld camera) is the utilisation of UAV (Unmanned Aerial vehicle). In this paper results from a PV solar Plant in Western Greece are introduced. The nominal power of the solar plant is 0, 9 MW and it is scanned both by a ground-controlled drone and by handheld equipment. It is essential to know all the factors effecting to results and also the time of scanning is important. The results done from the drone and from ground-based scanning are compared; also results from various altitudes and time of day are discussed.

The UAV (Unmanned Aerial Vehicle/RPAS (Remote Piloted Aircraft Systems) will give an excellent opportunity to monitor various targets which are impossible or difficult to access from the ground. Compared to fixed-wing and helicopter-based platforms it will give advantages but also this technology has limitations. One limitation is the weight of the equipment and the short operational range and short flight time. Also valid procedures must be created for different solutions in the future. The most important thing, as in all infrared thermography applications, is the proper interpretation of results.

9485-43, Session 7

The TEMPS program at NIST and its implications for optical properties metrology of laser-matter interaction

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Multiple processes involving directed energy beams to melt, sinter or evaporate materials can benefit from better understanding of emissive properties of materials in their solid, powder and liquid states. We present the current status of the TEMPS program, aimed at constructing a facility at NIST to characterize the radiative properties of materials at temperatures up to 2000 K and higher, under static as well as dynamic conditions of the heated spot (melt pool).

9485-44, Session 8

Three-dimensional non-destructive testing (NDT) in the infrared spectrum

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Three-dimensional (3D) vision scanning for metrology and inspection applications is an area that knows an increasing interest in the industry. This interest is driven by the recent advances in 3D technologies, permitting to attain high precision measurements at an affordable cost. 3D vision allows for the modelling and inspection of the visible surface of objects. When it is necessary to detect subsurface defects, active infrared thermography is one of the most used tools today for the non-destructive testing (NDT) of materials. Fusion of these two modalities allows the simultaneous detection of surface and subsurface defects and to visualize these defects overlaid on the 3D model of the scanned parts or their 3D computer-aided design (CAD).

In this work, we present a framework for automatically fusing 3D data (scanned or CAD) with the infrared thermal images for an NDT process in 3D space. The captured 3D images and their thermal infrared counterparts are aligned and fused using automatically detected features. This fusion is undergone on 3D space, thus allowing 3D visualization of subsurface defects on a 3D model (or CAD). Additionally, the defects are extracted using image processing techniques and overlaid over their virtual position in 3D space. Their positioning at a certain distance from the part 3D surface is proportional to the computed depth using phase image analysis in the Fourier domain. This depth represents the real position of the detected subsurface defect and is extracted using a sequence of thermal images.

The obtained results are promising and show how this new technology can be used efficiently in a combined NDT-Metrology analysis of manufactured parts, in areas such as aerospace and automotive, among others.

9485-45, Session 8

Thermographic inspection of external thermal insulation systems with mechanical fixing

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An external thermal Insulation composite system (ETICS) kit may include anchors to mechanically fix the insulation product onto the wall. This option increases safety over a simple bonded solution, but it is more expensive and needs more labor resources. The insulation material is then faced with render, which is applied directly, without any air gap. The rendering comprises one or more layers of coats with an embedded reinforcement. The commonest multi-coat rendering system consists of a base coat applied directly to the insulation product with a glass fiber mesh reinforcement, followed by a second base coat and then a very thin coat (key coat) that prepares the surface for the finishing and decorative coat. The system can be from 5 to 10 mm thick, with higher thicknesses possibly being associated with a two layers of fiber mesh reinforcement.

Nondestructive techniques may be useful when safety or quality control inspections are needed, being important to confirm the existence and distribution of the anchors. So, the main purpose of this work is to use the infrared thermography technique (IRT) in different ETICS solutions and assess its ability to detect anchors within it. The reliability of IRT will be tested using different ETICS configurations where the insulation products (expanded and extruded polystyrene, expanded cork and rock wool), the number of coats and thickness of the render system, and the type and color of the finishing coats are changed. An active thermography approach is first performed in laboratory conditions and then a passive inspection routine will be implemented for different environment conditions. At the end, a set of guidelines detect the presence and density of anchors during the ETICS inspection will be given.

9485-47, Session 8

Analysis of the relative merits of the 3-5 μm and the 8-12 ?m spectral bands using detected thermal contrast

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The two most important atmospheric transmission bands in the infrared occur at 3–5 μm and 8–12 μm respectively. For a given infrared detector a common question that continues to be asked is, of the two spectral bands, which gives the better performance? While seemly an innocent enough question, the literature attests it has not been without controversy. Conflicting and often contradictory results have been given that tend to reflect the predilections of the proponent as much as factors dependent upon, for example, the particular target to be detected, atmospheric transmittance, or detector performance. In this study an analysis designed to assess the relative merits of infrared detectors operating in the 3–5 μm and 8–12 μm spectral bands based on the recently defined figure of merit known as the detected thermal contrast is undertaken. The detected thermal contrast attempts to describe the overall performance of the sequence of events from the initial emission of thermal radiation at the surface of a target to the final measurable input signal seen in the detecting instrument. Under ideal limiting conditions typical of those found for many industrial and scientific applications, by considering targets whose spectral emissivities vary as a function of both wavelength and temperature, exact expressions based on the recently introduced polylogarithmic formulation of the problem are developed for both thermal and quantum detectors. It is found the 3–5 μm waveband for either detector type gives better performance for a range of different target types whose spectral emissivities are well known while differences between detector type is not as significant as one might initially expect. The work not only extends a number of approximation schemes that have been proposed and developed in the past where target emissivities as a function of the temperature only have been used, it also challenges a number of previously reported results.

9485-48, Session 9

Time-resolved multispectral imaging of combustion reaction

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Thermal infrared imaging is a field of science that evolves rapidly. Scientists have used for years the simplest tool: thermal broadband cameras. This allows to perform target characterization in both the longwave (LWIR) and midwave (MWIR) infrared spectral range. Infrared thermal imaging is used for a wide range of applications, especially in the combustion domain. For example, it can be used to follow combustion reactions, in order to characterize the injection and the ignition in a combustion chamber or even to observe gases produced by a flare stack. Most chemicals like carbon dioxide (CO2) selectively absorb/emit infrared radiation at discrete energies, i.e. over a very narrow spectral range. Temperatures derived from broadband imaging are erroneous when facing situations involving these gases. It is well known that spectral emissivity has to be taken into account in order to get reliable temperature values while this information is not available when using broadband imaging. In this work, combustion analysis of a candle was carried out using Telops MS-IR MW camera which allows multispectral imaging at a high frame rate. A motorized filter wheel allowing synchronized acquisitions on eight (8) different channels at a high frame rate is used to provide time-resolved multispectral imaging. Among the filters, seven distinct spectral filters and one neutral density filter, i.e. which corresponds to broadband imaging, were used for the experiments. The combustion recorded produced water and carbon dioxide, the latter being clearly observed in filters corresponding to its infrared signature. It was then possible to estimate the temperature of the gas plume by modeling its spectral profile. Comparison with temperatures obtained using conventional broadband imaging illustrates the benefits of time-resolved multispectral imaging for the characterization of combustion processes.

9485-49, Session 9

Thermal imaging of microfluidic systems as a model for investigating energy efficiency

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Microfluidic systems are miniaturized fluidic circuits that implement physical, chemical or biomedical processes (both for analysis or synthesis) on a micro-scale (microns to millimeters). Typically, a microfluidic device is fabricated on a thin substrate that hosts a fluidic network of chambers, reactors, conduits, channels, filters, and manifolds, possibly supplemented with micro-pumps and valves for fluid actuation and flow control. Heat and mass transfer, fluid phenomena (mixing, flow characteristics), and chemical kinetics can be imaged and visualized with an infrared camera to develop and validate engineering models of micro-scale processes. As a specific example, the efficiency of microfluidic heat exchangers, reactors, and pumps can be assessed by such thermal imaging. We present test devices and supporting instrumentation for thermal image analysis of a microfluidic heat exchanger, a bioreactor for algae culture, optically activated pumping and valves based on phase-change materials. Microfluidic devices are rapid-prototyped in clear plastics using a laser cutter and designed to facilitate thermal image analysis, as well as instrumentation with temperature, pressure, and flow-rate sensors. Energy efficiency can be assessed to determine the feasibility and effectiveness of microfluidic designs.

9485-50, Session 9

Spectrum infrared transmission study of water spray

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Water spray is widely used in fire prevention, metallurgy and heat radiation protection, because it has high infrared (IR) attenuation and is acquired easily everywhere. Research has proved this high IR attenuation comes from high IR absorption in droplet and intricate IR scatter between droplets. Recently, the calculation and theoretical analysis of water spray IR attenuation have been solved, where multi-scattering, distribution of droplet diameter, droplet density and water optical character in the infrared atmosphere window, etc. are considered. And a stair phenomenon in water spray spectrum IR transmission with droplet density invariable have been studied. However, is there similar phenomenon with spray water content increase and droplet diameter unchanged? And which droplet diameters are the most high IR absorption in the two IR atmosphere windows bands (3~5?m, 8~12?m)? These questions are still to be answered. Considering that Monte-Carlo Method (MCM) is usually used in calculating water spray

spectrum IR transmission, Single Diameter Monte Carlo Method (SDMCM) is used in this paper. Thus, the research can be concentrated on important factors such as spray IR transmission, the droplet character diameter which the minimum IR transmission of water spray in the IR atmosphere windows band is acquired, etc. In the calculation process, the water spray spectrum IR transmission is calculated with MIE scatter theory. The reasons for the phenomenon will be analyzed, and the character diameter with the minimum IR transmission of water spray will be calculated and accurately given.

9485-51, Session 9

Gas and flame detection and identification using uncooled MWIR imaging sensors

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Gas detectors are nowadays widely spread for safety purposes in industrial facilities. They are categorized by the type of gas they detect: combustible and/or toxic. Whereas electrochemical sensors have limited lifetime and maintenance issues, infrared sensors are reliable and free of maintenance devices used for detecting a wide variety of VoCs and inflammable gases such as hydrocarbon vapors. They usually work via a system of transmitters (light sources) which power is interfered when a gas is present in the optical path. A spectral analysis of this optical interference allows the gas detection and identification.

Optical flame detectors are sensors intended to sight and respond to the presence of a flame, faster than a smoke detector or a heat detector would do. Many of these systems operate in the infrared band in order to detect the heat radiation, most of the times by comparison of three specific wavelength bands.

Most of the present infrared gas and optical flame detectors traditionally make use of MWIR single point sensors rather than imaging sensors; this is mainly due to the lack of affordable imaging sensing technologies in this band of the infrared spectrum. However, the appearance of high-speed, uncooled imaging MWIR sensors made of VPD PbSe, with spectral detection range from 1 to 5 microns, opens the possibility to incorporate these sensors into gas and flame detection systems to allow area monitoring.

This paper reviews several experiments made using VPD PbSe imaging sensors for gas and flame detection. The data collected makes use of spectral filtering; the analysis of the multispectral cube will show the benefits of incorporating this technology for gas and flame area detection and identification

9485-52, Session 9

Detection of seal contamination in heat sealed food packaging based on active infrared thermography

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In the food industry, packaging is often applied to protect the product from the environment, assuring quality and safety throughout shelf life if properly performed. Packaging quality depends on the material used and the closure (seal). The material is selected based on the specific needs of the food product to be wrapped. However, proper closure of the package is often harder to achieve. One problem possibly jeopardizing seal quality is the presence of food particles in between the seal. Seal contamination can cause a decreased seal strength and thus an increased packaging failure risk. It can also trigger the formation of microchannels through which air and microorganisms can enter and spoil the enclosed food. Therefore, early detection and removal of seal-contaminated packages from the production chain is essential.

In this work an active thermography method using the heat of the sealing jaws as an excitation source is studied to detect seal contamination. The cooling profile of contaminated seals is recorded. Three data processing techniques, based on the slope of the cooling profile, a Fourier transform and a matched filter, are compared to quantify contamination. The effect of recording time and sampling frequency on detection efficiency is studied. High resolution digital images serve as a reference to quantify contamination. Although the thermograms have a lower spatial resolution than the digital images, heat dissipation enlarges defective regions enabling to detect small defects. Moreover, contrary to digital imaging, thermography is not limited to transparent packaging making it broadly applicable in the packaging industry.

9485-53, Session 10

Observation of temperature trace, induced by changing of temperature inside the human body, on the human body skin using commercially available IR camera

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We showed a possibility of observing of temperature trace on human body skin, caused by changing of temperature inside the human body due to water drinking. We use as a computer code that is available for treatment of images captured by commercially available IR camera, as well as our developed computer code for computer processing of these images. Using both codes we demonstrate clearly changing of human body skin temperature induced by water drinking. We discuss also another experiments dealing with the person which is drinking or eating. We analyze the response of human body on this and discuss a physical reason of observing phenomena.

Shown phenomena are very important for the detection of forbidden samples and substances cancelled inside the human body using non-destructive control without using X-rays. Early we have demonstrated such possibility using THz radiation. Carried out experiments can be used for solving of counter-terrorism problem.

9485-54, Session 10

Mass screening for infectious disease containment and pandemic outbreaks: misconceptions

Peter Leando, Compix Inc., Meditherm Inc., American College of Clinical Thermology Inc. (United States)

IR imaging in mass screening for the containment of pandemic disease is based on detecting a febril (fever) state in individuals.

The ability to use IR affectively for this is dependent on a good understanding of the physiology and physics related to the pathology that we are trying to screen for and is not restricted to temperature measurements alone. The radiometric thermal data processed during real-time imaging must include calibrated reference sources, thermal pattern recognition and comparative analysis between individual people being screened.

A screening test should have high 'sensitivity' rather than 'specificity' and to be effective the false negative rate must be very low. To achieve this the false positive rate will be high by necessity and so a 'secondary' level of screening can be implemented to bring the false positive rate to within a manageable level by the higher 'specificity' secondary level of screening.

This paper discusses the physiology of fever screening, experience based screening and operational protocols (operational problems and challenges), software assisted systems, operator / technician training and the future of IR screening as part of containment strategies for pandemic outbreaks.

9485-55, Session 10

3D medical thermography device

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Medical thermography has been demonstrated to be an effective, non-invasive tool for diagnosis. We present a novel system for 3D medical thermography using a mobile, handheld device, which offers significant advantages over existing fixed platform or 2D imaging solutions. The system is consists of a thermal-infrared camera, a conventional colour camera and a 3D range sensor rigidly attached in close proximity and mounted on an ergonomic handle. As a practitioner holding the device smoothly moves it around patients, the proposed system generates and builds up a precise 3D model by incorporating information from each new measurement in real-time. The geometric poses of the sensors are estimated simultaneously for all frames in the video sequence using a GPU-based SLAM solution. A dense voxel representation is optimized frame-to-frame, with each voxel assigned a color and a temperature through pose-based raycasting. The 3D voxel map can be visualized as a mesh with both color and temperature data represented simultaneously. The data is acquired in motion, thus it provides multiple points of view. When processed, these multiple points of view are adaptively combined by taking into account the reliability of each individual measurement which can vary due to a variety of factors such as angle of incidence, distance between the device and the patient and environmental sensor data or other factors influencing a confidence of the thermal infrared data when captured. High-resolution results are demonstrated for a number of body parts, and results suggest a strong utility for helping to detect and measure thermal irregularities in patients.

9485-56, Session 10

Cow's body region detection using a visual approach on thermal images

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Computer vision has assisted human activities in many fields, but has yet to be developed for livestock production.

The few applications existing are mainly using infrared (IR) cameras in environments where the mobility of the animal is reduced. The influence of the object pose on thermal images is well known. The Bag of visual Word (BoW) framework is famous for object recognition and pose estimation. Recognition of animals in images became very popular with the famous PASCAL VOC challenges, but almost no work has been conducted on thermal IR images. Among the few studies carried out on thermal image processing applications on animal sciences, a recent study has showed several regions on the cow body where measurements are easier to do. In this work we have assumed the body of a cow to be an object composed of multiple deformable objects, therefore we based our approach on the BoW framework. We experienced several image descriptors and clustering algorithms with the aim of comparing the result in terms of detection with the usual implementation of the BoW.

9485-57, Session PThu

Distinguishability of sensor fault from system fault

Morteza Taiebat, Farrokh Sassani, The Univ. of British Columbia (Canada)

There is increasing recognition that, if measurement data is to be used on-line, particularly for feedback control, then safety and reliability cannot be ensured without some form of on-line fault detection. The ability to differentiate between process/system faults and sensor malfunctions is crucial in the monitoring of a system, as different compensatory responses are required. System or process faults threaten the quality of the final product or action and may require immediate attention by the process operator, while malfunctioning unit can be either physically replaced or mathematically compensated for. The inherent difficulties of distinguishing the separate elements within a single signal are universally acknowledged. Meanwhile, feedback control adds to the complexity of fault detection in the system by masking measurement deviations that might indicate a fault, and by making it difficult to distinguish between sensor, actuator and plant failure. Present fault diagnosis methods have only studied sensor fault or system fault without considering the presence of the other. Indeed, they may occur at the same time. In this study we intend to develop a hypothesis to address this problem and currently we are focusing on the use of uncertainty modeling and belief propagation, based on probabilistic and empirical rules with considering sensor fault characteristics to distinguish between process and sensor faults. In contrast to traditional methods, which require strict duplication of sensor elements, we are aiming to employ minimum redundant sensors or functional redundancy for the observation of the process faults. We demonstrate through the belief propagation concept how sensor reading validation may lead to a certain distinguishability index. If the number of employed sensors is less than the estimated number of sensors required, this is a strong indication of the difficulty in distinguishing between sensor and system faults. Paper will encompass our approach and its application in industrial drying kiln.

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9486-2, Session 1

Detection of virus DNA by a surface-enhanced Raman scattering biosensor

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Surface-enhanced Raman scattering Sensors are characteristic of strong anti-interference, photobleaching-free and fingerprint signaling. However, Raman scattering is extremely inefficient. In addition, the SERS tags or substrates based on bare metal colloids suffer from instability and poor repeatability in an aqueous solution with high ionic strength. In this work, a sandwich-structured gold nanoparticle@Raman reporter@silica colloids haven been developed as the SERS tags. The silica outer-shell not only renders the water-solubility of colloids but also prevents from the leaking of Raman reporter molecule, which has much better stability and repeatability compared to bare metal nanoparticles. Such SERS tags are coupled to a periodic nano-array pattern on a solid-state chip to a form a plasmonic nano-architecture that has high-density of "hot spots". This SERS substrate can achieve strong electromagnetic filed enhancement in the three-dimensional space, which amplifies SERS signal remarkably. This SERS substrate has been used to detect a virus DNA with high sensitivity, low limit of detection and good repeatability. This plasmonic nano-architecture can be adapted as the SERS substrate for detection of a broad spectrum of biomolecules such as proteins, miRNA and small molecules.

9486-3, Session 1

iSERS: tissue-based cancer diagnostics using rationally designed plasmonic nanoparticles

Sebastian Schlücker, Yuying Zhang, Univ. Duisburg-Essen (Germany)

Protein localization in tissue sections by conventional immunohistochemistry (IHC) using enzyme-labeled antibodies is limited to the detection of a single target protein in a qualitative manner. In contrast, surface-enhanced Raman scattering (SERS)[1] offers a highly multiplexed, quantitative detection of numerous target molecules due to the small line width of vibrational Raman bands.

IHC based on SERS microscopy (iSERS), initially called immuno-Raman microspectroscopy[2], requires the rational design of functionalized noble metal nanoparticles as SERS labels for antibodies.[2-7] Different approaches to SERS nanoparticle probes with well-defined physical and chemical properties are described. Correlative LSPR/SEM/SERS microscopic experiments at the single-particle level reveal the underlying structure-activity relationships.[6]

Results from two-color iSERS experiments on prostate tissue specimens, targeting proteins such as p63 and PSA, are presented.[7] The combination of wide-field immunofluorescence and iSERS raster scanning, employing fluorophor- and SERS-labeled primary antibodies, allows a fast localization across large areas on biopsies. Quantitative spectral multiplexing is exemplified by cuvette experiments for various mixtures containing up to six different SERS "colors". Perspectives for iSERS as an innovative and highly promising nanobiophotonic imaging techniques are discussed.

[1] Angew. Chem. Int. Ed. 2014, 53, 4756-4795.

[2] J. Raman Spectrosc. 2006, 37, 719-721.

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[4] ChemPhysChem 2009, 10, 1344-1354.

[5] Analyst 2013, 138, 2224-2238.

[6] J. Biophoton. 2013, 6, 785-792.

[7] Nanoscale 2014, 6, 2361-2367.

9486-4, Session 2

Label free impedance detection of different biomarkers using a nanobio sensor array

Rahim Esfandyarpour, Ronald W. Davis, Zahra Koochak, Stanford Univ. (United States)

Detection of biological analytes is useful in various applications in biotechnology and personalized medicine. The analytes of interest may range from macromolecules, such as proteins and nucleic acids to viruses and whole cells. While each of them plays a vital part in life but there is something special about the proteins. Proteins are the key link between the processes of information and replication that take place on a genetic level and the infrastructure of living features. Detection of proteins and nucleic acids is often performed using optical fluorescence based techniques, which are more costly and timely than electrical detection due to the need for expensive and bulky optical equipment and the process of tagging. Thus, a robust label-free electrical detection technique can provide for a promising solution in lowering both reagent costs and instrumentation costs.

Thus, to overcome these various problems mentioned and to develop a more sensitive and label free platform, we developed a novel array of electrical nano-biosensors in a microfluidic channel, called nanoneedle biosensors.

Briefly, a nanoneedle biosensor is a real-time, label-free, matrix independent, direct electrical detection platform, which is capable of high sensitivity detection, measuring the change in impedance modulation, due to the presence or reaction of biomolecules such as proteins, nucleic acids and cells.

Previously in the Spring 2014 SPIE meeting, we presented the target cell detection results using our nan biosensors.

This time, the utility of this sensor in affinity biosensing for several different protein biomarkers is demonstrated. As a practical example with clinical relevance, detection of Vascular Endothelial Growth Factor (VEGF) in physiological salt buffer for cancer diagnosis is demonstrated.

Different generations of the sensors with various thicknesses and geometrical designs are developed and the sensitivity is improved.

We believe this work provides a strong starting point for a new class of electronic biosensing devices with the capability of rapid direct large-scale integration. Our demonstration of label-free and real-time detection of cancer biomarkers with this sensor can be envisioned to allow for point-of-care cancer diagnosis.

9486-5, Session 2

Light-directed functionalization methods for high-resolution optical fiber based biosensors

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Recent advances in miniaturization and analyte-sensitive fluorescent indicators make optical fiber biosensors promising alternatives to microelectrodes. Optical sensing offers several advantages over electrochemical methods including increased stability and better spatial control to monitor physiological processes at cellular resolutions. The distal end of an optical fiber can be functionalized with the different fluorophore/polymer combinations through mechanical, dip-coating, or photopolymerization techniques. Unlike mechanical and dip-coating schemes, photopolymerization can spatially confine the sensing layer in the vicinity of light in a more reproducible and controllable manner. The objective of this study was to design and optimize microscale fluorescence lifetime based optrodes using UV-induced photopolymerization. Among six commercially available acrylate based monomers, an acrylate-functionalized alkoxysilane monomer was selected and further modified to achieve stable entrapment of the oxygen sensitive porphyrin dye (PtTFPP) dye at the end of optical fibers. Sensitivity and response time were optimized by varying both the concentration of doped dye and the excitation power used for microtip growth at the end of 50 μm optical fibers. Selected monomer formulation and photopolymerization settings were also used to fabricate sensors at the end of tapered fibers as small as 5 μm. The resulting sensors showed linear response within the physiologically relevant range of oxygen concentrations and fast response times. While applied here to oxygen sensing, the photopolymer formulation and process parameters described are compatible with a wide range of available organic dyes and can be use to pattern arrays of spots, needles or more complex shapes at high spatial resolution.

9486-6, Session 2

Plasmonic-biosilica SERS sensors for ultra-sensitive immuno-assay detection

Jing Yang, Le Zhen, Fanghui Ren, Gregory L. Rorrer, Alan X. Wang, Oregon State Univ. (United States)

Immunoassay based on specific recognition between an antigen and a complementary antibody has become an essential and reliable tool for clinical diagnoses and diseases detection in recent years. Surface-enhanced Raman scattering (SERS) detection has attracted significant attention due to its narrow spectral bandwidth, immune to photo-bleaching, and fingerprint information of various molecules. Typically, SERS-based immunoassays are implemented on flat glass slides coated with colloidal nanoparticles. These substrates are inexpensive and easy to be functionalized, but the sensitivity is relatively low. Diatoms are photosynthetic micro-organisms that create their own skeletal shells of hydrated amorphous silica, called frustules, which naturally possess hierarchical micro- & nano-scale features that are extremely cumbersome and expensive to duplicate by top-down fabrication techniques. In this paper, we present the design, fabrication, and characterization of diatom-based SERS immunoassay by integrating Ag NPs into diatom frustules. The immunoassay was designed according to a standard sandwich protocol of enzyme-linked immunosorbent assay (ELISA). The model antibody, goat-anti-mouse immunoglobulin G (IgG) was first attached to the surface of Ag NPs. The antigen, mouse IgG was then immobilized onto the antibody-functionalized diatom frustules for the specific recognition. To evaluate the specific recognition between the antibody and the antigen, we challenged the immunoassay with a negative control IgG, human IgG. Afterward, the immunoassay was incubated with antibody-functionalized Au NPs, which were initially labeled with Raman reporter, 5,5'-Dithiobis-(2-Nitrobenzoic Acid) (DTNB). We achieved 10 pg/mL detection limit, which is 100? better than conventional colloidal SERS sensors in the comparison group.

9486-7, Session 2

Plasmonics-active gold nanostars for chemical and biological sensing using SERS detection

Yang Liu, Hsiangkuo Yuan, Andrew M. Fales, Tuan Vo-Dinh, Duke Univ. (United States)

Surface-enhanced Raman scattering (SERS) provides a non-destructive sensing method with high sensitivity and multiplex detection capability since SERS takes advantage of high enhancement from surface plasmon resonance and unique "fingerprint" spectral signature using Raman spectroscopy. Our group has developed a unique plasmonics-active nanoparticle, gold nanostars, with tunable plasmonics in near-infrared (NIR) "tissue optical window" without using toxic surfactant. We present their applications for chemical and biological sensing with SERS method as well as theoretical studies to investigate and confirm experimentally measured SERS results.

9486-8, Session 3

Surface-enhanced Raman scattering sensors on guided-mode resonance gratings

Jing Yang, Xinyuan Chong, Fanghui Ren, Alan X. Wang, Oregon State Univ. (United States)

Surface-enhanced Raman scattering (SERS) is a powerful technique which can provide ultra-sensitive and non-destructive characterization of various kinds of molecules. Although a peak enhancement factor (EF) as large as 1014 can be generated from the random "hot spots" that are created on metallic nanostructures, the density of such "hot spots" is extremely low, and this makes single molecule detection unpredictable. Therefore, a comprehensive enhancement mechanism that can provide a universal increase of the Raman signal intensity across the entire substrate is highly desirable for biomolecule detection. In this work, we design and fabricate a guided-mode-resonance (GMR) grating on indium-tin-oxide (ITO) thin film with resonant wavelength at 532 nm wavelength. A 100 nm thick spin-on-glass (SOG) is coated on top of the ITO grating. This thin layer of SOG will prevent direct contact of Ag NPs with the ITO grating to avoid strong damping effect, while still achieving reasonable coupling efficiency between the Ag NPs and ITO grating. The Ag NPs are self-assembled onto the SOG layer to provide a sufficient amount of "hot-spots" for SERS enhancement. In addition, the ITO grating exhibit great tolerance to fabrication deviations due to the strong refractive index contrast between the ITO and the SOG. Our ITO based SERS substrates demonstrate significant Raman enhancement capability and the quantitative SERS characterization of 5'-dithiobis (2-nitrobenzoic acid) (DTNB) on gratings showed that the LOD of the ITO gratings is 10 pM.

9486-9, Session 3

On-chip silicon photonic thermometers: from waveguide Bragg grating to ring resonators sensors

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Though today's resistance thermometers can routinely measure temperatures with uncertainties of 10 mK, they are sensitive to environmental variables such mechanical shock and humidity, which cause the sensor resistance to drift over time requiring expensive, time consuming calibrations. These fundamental limitations of resistance thermometry, as well as the desire to reduce sensor ownership cost has produced considerable interest in the development of photonic temperature sensors as an alternative to resistance thermometers. These innovative temperature sensors have the potential to leverage advances in frequency metrology to provide cost effective measurement solutions. Proposed sensor technologies range from temperature sensitive dyes to macro scale fiber Bragg grating (FBG). In this study we demonstrate that our 1st generation photonic thermometer, a silicon waveguide integrated with a Bragg grating (Si WBG), fabricated using CMOS technology and consisted of can be used to measure temperature changes over the range from 5 degC to 160 degC with a combined uncertainty [k = 2 (~ 2 sigma)] of 0.84 degC. In our work we also compare the performance of Si WBG sensors to ring resonators thermometers. Our preliminary results indicate that using photonic devices such as the ring resonator we can measure short term temperature fluctuations of ≈ 100 μK at room temperature.

9486-10, Session 3

Gold nanostars as building blocks for multiplexed chemical and biological sensing platforms

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Surface enhanced Raman scattering (SERS) is a phenomenon that relies on the ability of plasmonic nanoparticles to induce localized electromagnetic field enhancements, and for this reason they are a fundamental component of this spectroscopic technique. The possibility of achieving SERS signal enhancements high enough to enable sensitive identification of analytes down to the single molecule level is strictly related to the presence of the so-called "hot spots", which can be located at the vertices, edges, or crevices in isolated nanoparticles or at narrow junctions between assembled nanoparticles. In turn, the presence of finely tunable hot spots correlates to the possibility of applying SERS as a reliable spectroscopic technique in the analytical and biomedical fields.

In this talk I will first describe our efforts in optimizing synthetic strategies based on the interplay between kinetics and thermodynamics to finely tune the morphology of gold nanostars, with the goal of achieving extremely sharp structural features, ideal for near field localization. I will then describe our latest SERS-based sensing platform based on gold nanostars and will demonstrate how, by finely tuning the morphology of the nanostars, we were able to develop a multiplexed chemical sensor with limits of detection in the femtomolar regime and a SERS enhancement factor of 10^9. Furthermore, I will show how core-satellite assemblies of gold nanostars and nanospheres can be achieved with high regio-specificity by covalently linking only one spherical satellite per nanostar tip employing Raman-active molecular linkers and yield SERS enhancement factors of 10^10, which are extremely promising for applications in multiplexed chemical and biological sensing platforms.

9486-11, Session 3

Mid-infrared opto-nanofluidics for label-free on-chip chemical sensing

Pao T. Lin, Massachusetts Institute of Technology (United States)

A mid-infrared label-free chemical sensor was developed using opto-nanofluidics consisting of a Si-liquid-Si slot-structure. A broadband mid-IR lightwave can be strongly confined within a nanofluidic capillary by utilizing the large refractive index contrast between the liquid core waveguide and the Si cladding. Through an optical-field enhancement together with a direct interaction between the probe light and the analyte, the sensitivity for chemical detection is increased by 50 times when compared to evanescent-wave sensing. This spectral characterization distinguished several common organic liquids accurately, and could determine the ratio of chemical species at low concentration < 5 μL/mL in a mixture through spectral scanning over their characteristic mid-IR absorption peaks. The combination of CMOS-compatible planar mid-IR microphotonics, and a high-throughput nanofluidic sensor system, provides a unique platform for chemical detection.

9486-12, Session 3

Shifted excitation surface-enhanced Raman difference spectroscopy for ex vivo sensing of plasmonic nanoprobes

Martin Maiwald, Ferdinand-Braun-Institut (Germany); Janna K. Register, Andrew M. Fales, Duke Univ. (United States); Götz Erbert, Günther Tränkle, Ferdinand-Braun-Institut (Germany); Tuan Vo-Dinh, Duke Univ. (United States); Bernd Sumpf, Ferdinand-Braun-Institut (Germany)

This presentation describes the application of a dual-wavelength 785 nm diode laser for Shifted Excitation Raman Difference Spectroscopy (SERDS) to the detection of plasmonics-active nanoprobes. Plasmonics refers to the research area of enhanced electromagnetic properties of metallic nanostructures that produce ultrasensitive and selective detection technologies. Plasmonics-active nanosystems are at the cutting edge of biomedical 'theranostics' (the combination of both therapeutics and diagnostics) and show exciting promise for clinical translation to early disease detection. The plasmon resonance of anisotropic noble metal nanoparticles can be tuned to coincide with the "tissue optical window", allowing deeper penetration of the excitation laser wavelength. However, scattering from the skin's surface and autofluorescence from biological media can make in vivo detection challenging. Here, we present a dual-wavelength distributed Bragg reflector (DBR) Y branch diode laser as an exciation light source for SERDS. The laser chip contains two DBR gratings which are designed to provide two emission lines at 784.40 and 785.02 nm. An implemented Y-branch coupler realizes a common emission aperture and thus a common excitation spot on the sample. Transdermal SERDS measurements of plasmonic nanostars intradermally injected into ex vivo rat dorsal pelts were performed. Surface-enhanced Raman spectroscopy (SERS) affords the capability of sensitively reporting rich molecular information about multiple contrast agents simultaneously. In this presentation, we will show the combination of SERS with Shifted Excitation Raman Difference Spectroscopy for enhanced and background-free Raman spectroscopy to illustrate the potential of this setup for in vivo biosensing.

9486-13, Session 4

Enabling optical polarization sensing methods with liquid crystals

Paul Searcy, Daniel Phipps, Erika Petrak, Chris A. Toomey, Thomas G. Baur, Meadowlark Optics, Inc. (United States)

Meadowlark Optics has 30+ years working with polarized light in a huge gamut of application spaces from aerospace, astronomy, semiconductor manufacturing, military, bioengineering and telecommunications. This makes us uniquely positioned to explain the pros and cons of successfully using Liquid Crystals in many different applications. Fundamentally, Liquid Crystals (LCs) are becoming ubiquitous tools for optical designers but have complex trade-offs when considering all the different parameters of LCs. We will discuss the pros and cons of Nematic, Ferroelectric, Polymer-Dispersed, Twisted (and Super Twisted) Nematic, Sheared, and Vertically Aligned technologies both in the context of Single Pixel and Spatial Light Modulator applications. Explaining the strengths and weaknesses of different approaches we enable the rest of the optical sensing community to make optimal application specific choices.

9486-14, Session 4

Dispersive Raman spectroscopy excited at 1064nm to classify the botanic origin of honeys from Calabria and quantify the sugar profile

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Calabria is a nice region located in the South of Italy. Its rich vegetation and pristine habitat are ideal conditions for the production of excellent honey. One of the major needs of producers is the availability of innovative devices for non-destructive and quick assessment of the honey quality, that is, the botanic origin together with the sugar profile. Optical spectroscopy has been recently recognized as a convenient technique which is particularly suitable for non destructive testings of intact food. Absorption, fluorescence, and Raman spectroscopy demonstrated effectiveness also for honey analyses, especially for distinguishing the botanic origin, for revealing adulterated samples, and for quantifying glucose and fructose as main sugars.

The present paper makes use of a compact device for performing Raman spectroscopy with excitation at 1064nm and a grating-based detecting unit. The long excitation wavelength makes it possible to avoid fluorescence effects that could overcome the weak Raman signal, while the dispersive detection scheme makes the instrument a compact and portable unit.

A set of 13 honey samples was considered, made of 3 different botanic origins, 5 of chestnut, 5 of citrus, and 3 of acacia, respectively. The sugar profile of these samples was available, which was previously obtained by means of destructive analytical measurements.

The Raman spectra were firstly processed by means of the Principal Component Analysis, then by the Linear Discriminant Analysis thus obtaining an excellent clustering according to the botanic origin. Moreover, a predictive model was created using the Partial least Square method for quantitatively predicting the content of the content of sugars. Good results were achieved for quantifying the most abundant sugars, that are: glucose, fructose, isomaltose, maltose, as well as other minor sugars such as erlose, theralose and kojibiose.

9486-15, Session 4

FTIR monitoring of methane from a local landfill

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From anthropogenic sources to natural oceanic emissions, the concentration of methane in the atmosphere has more than doubled in the last 200 years. Since methane represents a global warming potential 34 times an equivalent mass of carbon dioxide, monitoring this species is of great interest. In terms of anthropogenic emissions, landfills represent a significant source of atmospheric methane. We developed a method for sensing and monitoring ambient concentrations of methane by combining FTIR technology with an in-house Excel-based algorithm to extract methane concentrations from FTIR generated rovibrational data.

The Craighead County Legacy Landfill in NE Arkansas is not currently required to collect combustable gases under the landfill NSPS/EG, although that may change in the future. To assess the methane monitoring capability of FTIR method discussed here, gas samples from a number of locations surrounding the landfill were obtained using a set of evacuated stainless steel cylinders. For each sample, a precise location was determined via GPS along with wind speed and weather conditions. Sample cylinders were then connected, in turn, to a research grade FTIR instrument equipped with a 35 m variable absorption path length gas cell. FTIR spectra were recorded for each sample at a spectral resolution of 0.125 cm-1. From each rovbrational spectrum, a methane concentration was extracted by fitting the in-house Excel-based simulation to the data. Based on a set of preliminary measurements and subsequent analysis of gas samples obtained at various locations around the landfill, the methane concentrations are in the 5-25 ppm range near the site depending of course upon prevailing weather conditions. In this work, we will describe the method and present preliminary analysis of the resulting measurements.

9486-16, Session 4

A method for continuous in-situ pathlength calibration of integrating sphere based gas cells

Sarah Bergin, Jane Hodgkinson, Daniel Francis, Ralph P. Tatam, Cranfield Univ. (United Kingdom)

Growing concerns regarding occupational safety and emission control are driving a demand for industrial gas sensors. Gas sensors based on tunable diode laser spectroscopy provide high specificity to the required gas, fast response, repeatable measurements and low (ppm) limits of detection. However when introduced to an industrial setting, the stability of these systems is subjected to further challenges, including maintenance of precise optical alignment in the face of ambient temperature changes and mechanical vibration.

Though originally used to measure the total flux of light sources, the integrating sphere has gained attention as a multipass absorption cell. Integrating spheres consist of a highly reflective surface, providing multiple diffuse reflections, tolerance to misalignment, the ability to measure turbid or irregular samples and the elimination of optical interference fringes. However, their mean pathlength is heavily dependent on sphere wall reflectivity. Consequently, contamination can reduce the pathlength considerably, affecting the calibration.

We introduce a novel approach to continuous in-situ pathlength calibration of an integrating sphere, which compensates for both component degradation and changes in pathlength due to cell wall contamination. In this way the gas absorption coefficient can be determined continuously without needing to remove and clean the sphere. Results are presented for detection of methane at 1651nm. These methods have the potential for extension to other gases such as CO2, CO, H2S, NOx and other gases.

9486-17, Session 4

Real-time measurement of the NO2 concentration in ambient air using a multi-mode diode laser and cavity enhanced multiple line integrated absorption spectroscopy

Michael Fernez, Andreas Karpf, Gottipaty N. Rao, Adelphi Univ. (United States)

We report on the development and demonstration of a highly sensitive trace gas sensor using a multimode diode laser, and cavity enhanced multiple line integrated absorption spectroscopy. The sensor was tested using known concentrations of NO2 mixed in Zero Air and was used to measure the concentration of NO2 in ambient air in our laboratory. The broad frequency range of a multi-mode Fabry-Perot diode laser covered a large number of absorption lines of NO2 which enabled us to detect the absorption signal corresponding to a large number of rovibronic NO2 transitions simultaneously. The use of a high finesse cavity enhances the sensitivity of the detector by providing a pathlength on the order of 1 km in a small volume. Off-axis alignment excites a large number of cavity modes which improves the signal strength and simultaneously reduces the detector's susceptibility to vibration. Relatively high laser power (~300 mW) was used to compensate for the low coupling efficiency of a broad linewidth laser to the optical cavity. The NO2 concentration in ambient air was measured

and found to be approximately 15 ppb. Low concentration mixtures of NO2 in Zero Air were used to calibrate the device and determine the detector's sensitivity: The device's sensitivity was found to be approximately 1 ppb.

9486-18, Session 5

Active stand-off detection of gas leaks using an open-path quantum cascade laser sensor in a backscatter configuration

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Fugitive gas emission from agricultural or industrial plants are an important environmental concern as it contributes to the global increase of greenhouse gas concentration. This study presents gas concentration measurements using a quantum cascade laser open path system (QCLOPS). The system retrieves the path-averaged concentration of N2O by collecting the backscattered light from topographic target. The gas concentration measurements presented in this work have a high temporal resolution (68 ms) and are achieved at sufficient range (40 m, ~ 130 feet) with a precision of ± 0.2 ppm. Given these characteristics, this system is ideal for gas leak localization and quantification. The instrument used is a monostatic system using a tunable quantum cascade laser emitting at ~ 7.7 μm wavelength pointed at a pseudo-Lambertian gold target. The backscattered radiation is collected by a Newtonian receiver telescope and focused on an infrared light detector. A 1 mL puff of pure N2O is then released along the optical path to simulate a gas leak. The measured absorption spectrum of N2O is obtained using the thermal intra-pulse frequency chirp of a pulsed DFB quantum cascade laser. Then, the least-squares fitting technique is implemented to fit the measured spectrum with a reference spectrum. The coefficients resulting from the fitting are used to retrieve the path-averaged concentration values of N2O.

9486-19, Session 5

Monitoring urban atmospheric ozone and ethylene by infrared DIAL remote sensing

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Experimental results to underline the dynamics of ethylene and ozone in presence of urban nitrogen oxides are presented. We also demonstrate the effective role played by ethylene, as representative of volatile organic compounds, in the formation of urban ozone. The campaign proceeds with earlier investigations of ozone dynamics in response to urban human activity.

The main source of pollution is attributed to vehicle exhaust and to a very low extent to wind transport of ethylene from the southern industrial region. The area monitored by the DIAL is a residential area located north-west of Madrid (40º 27' N, 3º 44' W, 680m above sea level). Measurements spanned over several days between 10:00 and 20:00 with a standard deviation that varied between 1% and 7%. The standard deviation of 7% is an equivalent measurement uncertainty of almost 2-ppb when averaging 200 pulse pairs.

Correlation between ozone concentration and ethylene, as volatile organic compounds representative, was demonstrated. Our observations are additionally supported by a basic photochemical smog model that indeed suggests a direct correlation between the C2H4 evolution and that of O3 under similar conditions for the urban atmosphere under investigation.

9486-20, Session 5

Development of Differential Absorption LIdar (DIAL) for Detection of CO2, CH4 and PM in Alberta

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Rapid expansion of the oil and gas industry in Alberta, including the oil sands, has challenged the Alberta Government to keep pace in its efforts to monitor and mitigate the environmental impacts of development. The limitations of current monitoring systems has pushed the provincial government to seek out advanced sensing technologies such as satellite imagery and laser based sensors. Space Dynamics Laboratory (SDL) of Utah State University, in cooperation with Alberta Environmental Monitoring, Evaluation and Reporting Agency (AEMERA), has developed North America's first mobile differential absorption lidar (DIAL) system designed specifically for emissions measurement. This instrument is housed inside a 36' trailer which allows for mobility to travel across Alberta to characterize source emissions and to locate fugitive leaks. DIAL is capable of measuring concentrations for carbon dioxide (CO2) and methane (CH4) at ranges of up to 3 km with a spatial resolution of 10 meters. DIAL can map both CO2 and CH4, as well as particulate matter (PM) in a linear fashion; by scanning the laser beam in both azimuth and elevation DIAL can create images of emissions in two dimensions. DIAL imagery may be used to understand and control production practices, characterize source emissions, to determine emission factors, locate fugitive leaks, assess plume dispersion and confirm air dispersion modeling. A system overview of the DIAL instrument and some representative results will be discussed.

9486-21, Session 5

Combined microphone array and lock-in amplifier operations for outdoor photo-acoustic sensing

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Mid-infrared (MIR) standoff photoacoustic (PA) sensing of explosive chemicals and nerve gas stimulants at calibrated concentration have been demonstrated in door. When they are operated out door, array beam forming technique has to be employed to reject ambient noise and enhance signal. Lock-in amplifier usually needs to be used to achieve weak signal detection in a noisy environment. If we can combine these two techniques we will be able to reject both spatial and temporal noise and achieve great signal to noise ratio (SNR) performance. From the best of our knowledge no literature has described how to combine these two techniques. In this work we demonstrated combined array and lock in amplifier operation in outdoor environment. A simplified system includes a signal generator, a speaker source, a lock in amplifier, 4 spy-phones with 4 parabolic reflectors to collect the acoustic signal, a National-Instrument NI6259 data acquisition system with both A to D (ADC) and D to A converters (DAC), and a PC. To combine these two techniques, each of the array collected signals was digitized by the ADC. Their path delays were adjusted in the computer to synchronize the phase. By using a PC controlled ADC the processing time is very long (~1s). To synchronize them without using costly high-speed customer made hardware, we delayed the reference signal by send it through the

same ADC- PC-DAC path as the array signals. By doing so, a good lock-in operation with stable phase was obtained.

9486-22, Session 5

Standoff detection of trace chemicals with laser dispersion spectrometer

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Standoff and remote trace gas detection plays an important role in numerous applications including industrial monitoring and security. This sensing approach can be also very beneficial in environmental monitoring, e.g. when quantifying emissions from distributed sources like wetlands or water reservoirs. Using single instrument that covers large area with path-integrated detection can significantly reduce deployment costs. Unfortunately, remote/standoff arrangement is also technically challenging: power that is received by the photodetector can strongly fluctuate (especially when diffuse optical targets are used).

When high sensitivity is needed, wavelength modulation spectroscopy (WMS) is typically used. However, because in WMS spectroscopic information is encoded in the intensity of light, optical power fluctuations larger than two orders of magnitude will reduce accuracy of this technique (even when 2f/1f normalization is applied). Chirped Lasers Dispersion Spectroscopy (CLaDS) is an alternative method for remote sensing applications in which high accuracy is required [Wysocki and Weidmann OE18, p26123, 2010]. In CLaDS, the spectroscopic information is encoded in the frequency/phase domain rather than amplitude which makes CLaDS signal immune to optical power fluctuations. Up to date chemical detection with CLaDS was demonstrated using retro-reflectors with only few tests being performed using diffusive optical targets [Nikodem et al. APB, DOI:10.1007/s00340-014-5938-3]. In this paper we will present our studies on 1651nm CLaDS-based open-path methane sensing using scattering targets. Detection limit for environmental methane detection at trace levels will be experimentally determined and technical requirements for this instrument will be analyzed (including optical power levels, maximum target distance and optical target type).

9486-23, Session 6

Microfluidics for spectrochemical applications

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There is no doubt that microfluidics has been receiving significant attention for chemical and biochemical analysis applications. A number of technologies have been used to fabricate microfluidic channels. Such technologies ranged from wet chemical etching to deep reactive ion etching. More recently, 3d-printing has been employed to make 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 recent examples.

9486-24, Session 6

Multispectral light scattering imaging and multivariate analysis of airborne particulates

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Light scattering patterns from non-spherical particles and aggregates exhibit complex structure that is only revealed when observing in two angular dimensions. However, due to the varied shape and packing of such aerosols, the rich structure in the two-dimensional angular optical scattering (TAOS) pattern varies from particle to particle. We examine two-dimensional light scattering patterns obtained at multiple wavelengths using a single CCD camera with minimal cross talk between channels. The integration of the approach with a single CCD camera assures that data is acquired within the same solid angle and orientation. Since the optical size of the scattering particle is inversely proportional to the illuminating wavelength, the spectrally resolved scattering information provides characteristic information about the airborne particles simultaneously in two different scaling regimes. The simultaneous acquisition of data from airborne particulate matter at two different wavelengths allows for additional degrees of freedom in the analysis and characterization of the aerosols. Whereas our previous multivariate analyses of aerosol particles has relied solely on spatial frequency components, our present approach attempts to incorporate the relative symmetry of the particle-detector system while extracting information content from both spectral channels. In addition to single channel data, this current approach also examines relative metrics. Consequently, we have begun to employ multivariate techniques based on novel morphological descriptors in order to classify "unknown" particles within a database of TAOS patterns from known aerosols utilizing both spectral and spatial information acquired. A comparison is made among several different classification metrics, all of which show improved classification capabilities relative to our previous approaches.

9486-25, Session 6

Universal optical platform for monitoring of bioprocess variables

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The main bioprocess variables that are continuously measured are pH, dissolved oxygen (DO), and dissolved carbon dioxide (DCO2). Less common variables are redox, concentrations of substrate and product concentrations, product activity, etc. Recently, pH and DO are measured using optical chemical sensors due to their small form factor and convenience in use. These sensors are typically interrogated using a lab grade spectrometer, or with the help of a low-cost, tailor-made optoelectronic transducer that is designed around the optical sensor. In this contribution, we are presenting a new class of optoelectronic transducers that are capable of monitoring several different optical sensors without the need to switch the optics or hardware when changing the type of sensor. This allows flexibility closer to the lab-grade devices at a price point of a dedicated sensor.

In this work, we are demonstrating a universal optical platform capable of monitoring pH or DO sensors. It uses the principle of ratiometric fluorescence measurements for pH, and fluorescence lifetime measurements for DO. The platform is capable of seamlessly switching between these two modes. It is also capable of auto recognition of the sensor type. The platform can operate both with patch-type or fiber optic type of sensors. The platform has measurement accuracy of about 0.08 pH units and approximately 5% air saturation with oxygen. Additionally, an approach to obtain identical calibrations between several devices is presented.

The described platform has been tested in actual bioprocesses and has been found adequate for continuous bioprocess monitoring.

9486-26, Session 6

Prediction of carp aggregation based on sensory data

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This work presents an agent-based mathematical model to simulate the

aggregation of carp, a harmful fish in North America, using the newly observed data as initial conditions. The referred mathematical model is derived from the following assumptions: (1) instead of the consensus among every carps involved in the aggregation, the aggregation of carp is completely a random and spontaneous physical behavior of numerous of independent carp; (2) carp aggregation is a collective effect of inter-carp and carp-environment interaction; (3) the inter-carp interaction can be derived from the statistical analytics about large-scale observed data. As a variance of molecular dynamics method, the proposed mathematical model is based on empirical inter-carp force field, whose effect is featured with repulsion, parallel orientation, attraction, out-of-perception zone, and blind angle of carp. By employing entropy theory and addressed inter-carp force field, the aggregation behavior of carp is investigated. Preliminary simulation results about the aggregation of small number of carps within simple environment are provided. To solve real world large-scale problem, a divide-and-conquer strategy will be employed to soothe the inhibitive computational cost of model, namely the targeting lake will be partitioned into multiple overlapping or non-overlapping subdomains (or cells), which can be investigated independently; in addition, machine learning techniques will be employed to measure the aggregation likelihood of each cell. The addressed model will be validated using real-world sensory data.

9486-27, Session PTue

Polymethyl-methacrylate nanoparticles as carrier for theranostic agents into cells

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Nanoparticle and nanomaterial technologies in the biomedical field are significantly impacting the development of both therapeutic and diagnostic (theranostic) agents. The use of an antisense oligonucleotide which acts as molecular beacon (MB) being able to generate a fluorescent signal when it hybridizes with the target mRNA, may represent an innovative strategy that conjugates the ability of sensing specific mRNA with the pharmacological silencing activity preventing the overexpression of proteins associated to pathologic conditions. This oligonucleotide optical switch constitutes then a theranostic agent, which is a highly promising and fascinating tool for simultaneous intracellular detection and silencing of specific mRNA molecules. In this paper, the mRNA specific for survivin was chosen as target: survivin is an intracellular protein belonging to the family of Inhibitors of Apoptosis Proteins (IAP), through which tumor cells can acquire resistance to apoptosis and its over-expression was demonstrated in different tumors of various localizations, such as breast, esophagus, pancreas, colon, stomach, and others.

Polymethyl-methacrylate (PMMA) nanoparticles (NPs) were used as nanocarriers to enter the cells and a complete optical characterization of the nanostructures used to internalize MBs was performed. PMMA NPs are intrinsically fluorescent, thanks to the presence of fluorescein entrapped within their core during their synthesis, in order to determine optically their localization.

Two different MBs for survivin mRNA were used, having at their extremities Atto647N (λabs 644 nm, λem 669 nm) and Blackberry Quencher 650 (?max ~ 650 nm, useful absorbance between 550 and 750 nm) as fluorophore/quencher pair. They were characterized in vitro and their functionality was verified both in solution and after their immobilization onto the PMMA NPs. In particular, the sensitivity of the MBs was investigated by recording the fluorescence of the MB in different buffers and after incubation for different times with increasing concentrations of the target. PMMA NPs, and MB-adsorbed onto them were then tested on human lung carcinoma A549 cells and on human dermal fibroblasts (HDFa) as negative controls, in terms of cell vitality and internalization. These experiments provided clear evidence of the subcellular distribution of nanoparticles in living cells and of their ability to promote the MB internalization.

We have shown that oligonucleotide optical switches, together with NPs, can play a fundamental role in achieving quantitative information on intracellular events. The conducted analytical characterization demonstrated that they can be used not only as simple on-off elements but also as real sensors.

9486-28, Session PTue

Global nuclear radiation monitoring using plants

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Plants exhibit complex responses environmental changes such as temperature, water, airborne pollutants, and soil contents. Our work focuses on plant responses to nuclear radiation – with the goal of monitoring plant responses as benchmarks for detection and dosimetry. In this study, we have so far included the following plants: Cactus, Arabidopsis, Dwarf mango (pine), Euymus, Azela, and Arborvitae. We observed that inside these plants Chlorophyll-a to Chlorophyll-b ratio can be changed according to the accumlated total radiation dose. The recovery processes and speed are different for different plants. Some plants recover fast, some slow, and some never recover and die. The full photoluminescence (PL) spectral are correlated to the recovery and dying process.

In our experiment, an InGaN blue laser (405nm) is used as the pump laser. The PL spectrum shows a relatively weak and broad green peak near 550 nm (carotenoids) and two narrower and stronger peaks near 685nm (chlorophyll-a) and 735 nm (chlorophyll-b). Sample tree subjects were placed at a distance of 3m from NIST BT-2 reactor gate capable of producing a maximum neutron field dose rate of about 2x108 /(cm2*sec).

Our results shows that some plants are sensitive to nuclear radiation and some are less. We can use their characteristics to do differential detection, extract nuclear activity information out of measurement results, and avoid false alarms produced by environmental changes. Certainly the ultimate verification can be obtained from genetic information, which only needs to be done when we have seen noticeable changes on plant optical spectra, mechanical strength and electrical characteristics.

9486-29, Session PTue

A plastic optical fiber biosensor for e. coli

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This work presents a novel, fast response time, plastic optic fiber (POF) biosensor to detect Escherichia coli. Different forms of probes in U-shaped format were tested: U-shaped with different radiuses, coil-shaped and meander-shaped. In the calibration process we used solutions of sucrose for obtaining refractive indexes (RI) in the range 1.33 – 1.39 IR equivalent of water and bacteria, respectively. The POF probes were functionalized with antibody anti-Escherichia coli serotype O55 and tested with bacteria concentrations of 104, 106 and 108 colonies forming unities/mL (CFU/mL). The optoelectronic setup consists of an 880 nm LED connected to the U-shaped probe driven by a current source controlled by an Arduino Microcontroller. In the opposite fiber end, the light received by a photodiode is amplified and read by the A/D port of the microcontroller. The output

voltage decreases as the external RI increases, accordingly to the bacteria that is captured by the antibody fixed in the biosensor. The paper presents results obtained with the different shapes of probes tested with the same setup and biochemical protocol. In conclusion the system shows good possibilities of having concentration measurements results in less than 10 minutes with uncertainty of 10-4 RIU enabling in a future capacity to read concentration of 105 and 103 CFU/mL.

9486-30, Session PTue

Fabrication and characterization of Pd nanocube-reduced graphene oxide composite based hydrogen sensor

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Graphene-supported palladium (Pd) nanocubes were synthesized by a simple chemical method for hydrogen sensing. Pd nanocubes of 25, 40, 55, 70 and 85 nm sizes were synthesized in colloidal state by a chemical route in two-steps (seed-mediated growth) and then, simply reduced into graphene flakes by hydrazine in a simple one-step process. The hydrogen-sensing and electrocatalyst properties of the new Pd nanocube-graphene hybrid were investigated in detail. The resistivity-type sensor that used the Pd cube-graphene hybrid had a detectable range from 10,000 ppm to 10 ppm with good sensitivity and linearity at room temperature. Our experiment showed that the Pd cube-graphene hybrid with bigger Pd nanocubes not only showed better response to H2 gas molecules but also maintained its excellent H2 sensing properties even with increases in working temperature. The effects of Pd nanocube size on the H2 sensing performance of the Pd cube-graphene hybrid was explained by the spillover mechanism in this work.

9486-31, Session PTue

Oil and gas deposits determination by ultraspectral lidar

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GeoChemical surveys of hydrocarbon deposits based on detection of the oil and gas migration as well as the other molecules such as CyHx, H2S, CO, CO2. The migration leads to a change of the physical properties of the rocks above the hydrocarbon (methane, propane) deposit and anomalous concentrations of hydrocarbon gases in an atmospheric boundary layer.

Laser sensing is a highly effective method for the deposit exploration. We present a Raman lidar with ultraspectral resolution for airborne oil&gas exploration and pipeline leakage detection. Tests were carried out on the gas pipeline Urengoy-Novopskov. The experiments were carried out to detect leaks on the working section of pipeline with an internal pressure of 60-70 bar. Test flights show the level of sensitivity about 6 ppm (methane) and 3 ppm (hydrogen sulfide) with the measurements at 50 to 500 m flight altitudes.

The probing is done by a compact pulsed diode pumped Nd:YLF laser (50 mJ ,6 ns, 100 Hz) with KTP ISHG (50% conversion efficiency) and BBO frequency shifting (261.7 nm, 6-10mJ).

Ultraspectral resolution of the double polychromator (3600 mm-1, dλ/dl=0.224 nm/mm) reliably differentiates methane (283.31 and 284.42 nm), nitrogen (278.69 nm), and hydrogen sulfide (280.89 nm) what ensures reliable 80% HHG detection for the integration of seismic prospecting and laser remote sensing.

9486-32, Session PTue

Lidar for monitoring methane hydrate in the arctic permafrost

Alexsandr S. Grishkanich, Alexsandr P. Zhevlakov, Sergey V. Kascheev, Victor G. Bespalov, Valentin V. Elizarov, National Research Univ. of Information Technologies, Mechanics and Optics (Russian Federation); Alexsandr Gusarov, Belgian Nuclear Research Ctr. (Belgium)

Over the past 100 years, the rate of the temperature change in the Arctic increased almost twice compared to the average rate of warming on the Earth. Preliminary estimations predict the fast and wide degradation of permafrost across the Arctic by the year 2100. Deconservation of 0.1% of the organic carbon from the upper 100 m layer of permafrost (about 10,000 Gt of carbon in the form of CH4) may double the atmospheric methane with radiation activity about 20 times higher than that of CO2.

The advantages of Raman-lidar for monitoring of methane hydrate from the permafrost are to create an alternative to the conventional visual monitoring and sampling, which are more expensive and inefficient in the Arctic.

CH4 frequency spectra are characterized by isotopic shifts, depend on the isotopic mass (and neutrons) and can be extremely fine. For example, C14 shifts from the relatively stable C12 by only 12.4•10-3 cm-1 and hyper/ultraspectral (λ/Δλ>>100) resolution measurements required for their identification. Hyperspectral resolution helps to avoid the overlapping of spectral lines, resolves the isotopic shifts in the Stokes spectra, and allows determine the isotopic composition. C14/C12 ratio of the composition identifies the source of the carbon emission (permafrost or oil deposits).

We developed on-board Raman lidar which allows methane pockets detection, and classifies parameters (C14/C12 ratio) of the permafrost anomalies. The lidar is based on Nd: YAG laser (266 nm, 50 mJ, 5 ns, 100 Hz) and hyperspectral resolution detection system for resolving the isotopic shifts in the Stokes spectra.

9486-33, Session PTue

Monitoring radioactive contamination by hyperspectral lidar

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There are already significant amounts of hazardous radioactive substances in the world. It, potentially, leads to a major damage and contamination of large areas. Long-lived isotopes of cesium and strontium, as well as compounds of transuranic elements define a long-term radioactive contamination.

Lidars can be effective for monitoring of the radioactive contamination. Laser induced fluorescence of UO2 nuclear facility accidental release has characteristic spectral structure and consists of a limited (6-8) number of lines in 470-530 nm range. (UO2) 2 + uranyl ions can form fluorescent compounds in water, soil, or material surfaces. It allows detect nuclear fuel components in the environment. Fluorescence of all interfering impurities completely stops in 1-2 ms after the laser probe, and spectral identification of the uranyl salts is trustable and effective after the proper delay since the intensity of fluorescence of the uranyl compounds decreases by only 10-15%.

The most effective fluorescence of the salts, and therefore the most sensitive detection was achieved with a pulsed Nd: YAG laser (266 nm, 20 mJ, 6 ns, 100 Hz). The sensitivity was determined by lidar calibration based on the samples with a known amount of uranium. Preliminary results show, that the lidar can detect uranium oxides with concentration of 500 ppb on 100 m2 surface.

The alternative approach is to use Raman-scattering circuit. We demonstrate effective detection of U235O2, U238O2, Sr90 and Cs137 spectral shifts. It allows remote (100 – 500 m) detection of radionuclides with 1 ppm concentration.

9486-34, Session PTue

Chemical agent registration method on the basis of surface optical sensitization and surface plasmon resonance

Sergei Vinogradov, Michail Kononov, A. M. Prokhorov General Physics Institute (Russian Federation)

There are some methods of different molecules and atoms sensing, some of them are working on the basis of surface plasmon resonance (SPR). We represent the new approach in chemical sensing based on superposition of SPR and effect of surface optical sensitization of silver halide. Commonly chemical sensor consists of two main parts namely a sensing part and a registration part. In our approach we used widely known attenuated total reflection method of SPR generation in the registration part of our setup. However in sensing part we used the new approach on the base of surface optical sensitization of thin silver halide nanocrystal films. Samples of sensing multilayer structure consisted of silver layer (about 50 nm), protective thin aluminum oxide film (about 5 nm) and polycrystalline silver iodide layer. All layers were deposited onto flat polish glass substate. As a model agent which must registers arsenazo III was used. Arsenazo III in the form of a powder was inserted in the optically transparent camera near sensing samples which were exposed by laser light with wavelength 543,5 nm. SPR was excited by laser light with wavelength 632,8 nm. All experiments were made in the normal conditions. As the result, we obtained SPR signal changes from multilayer structure in presence of arsenazo III molecules in gas phase. We estimate sensitivity of our method as 10^10 particles in cm^3 while method selectivity determines by chemical agent absorption spectrum.

9486-35, Session PTue

Fabrication and characterization of Ag/ZnO nanoparticles-reduced graphene oxide hybrid based acetylene sensor

A .S. M. Iftekhar Uddin, Gwiy Sang Chung, Univ. of Ulsan (Korea, Republic of)

This paper describes the synthesis and fabrication of silver (Ag)/ZnO nanoparticles (NPs)-reduced graphene oxide (rGO) hybrid via a chemical method with graphene oxide (GO), AgNO3 and Zn(NO3)2.6H2O as the precursors. The physical and structural properties of the synthesized materials were characterized by field emission scanning electron microscopy (FESEM), transmission electron microscopy (TEM), energy dispersive spectroscopy (EDS), Fourier transform infrared spectroscopy (FTIR) and X-ray diffraction (XRD). The sensing properties of the hybrid materials were characterized as the function of temperature, response, response/recovery time, linearity, reproducibility and selectivity. The morphological studies reveal that the synthesized material exhibited thin rGO layers decorated with the mixer of tiny Ag and ZnO NPs where rGO supposedly acted as a template in the synthesis process that promoted the preferential attachment of Ag and ZnO NPs and prevented the agglomeration of the nanoparticles. The structural and elemental characterization demonstrated the formation of high purity sensing material and good agreement with the standard crystalline structure. Several sensing material samples were prepared by varying the Ag contents to determine the optimum material ratio. At 150oC, 3wt% Ag/ZnO-rGO specimen showed maximum sensor response (S = Ra/Rg) of 35 to 1000 ppm acetylene gas concentration in air atmosphere. The synthesized hybrid also showed fast response/recovery time (25/80 sec) with good linearity, good reproducibility and excellent selectivity.

9486-36, Session PTue

Quality control in the recycling stream of PVC cable waste by hyperspectral imaging

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In recent years recycling is gaining a key role in the manufacturing industry. The use of recycled materials in the production of new goods has the double advantage of saving energy and natural resources, moreover from an economic point of view, recycled materials are in general cheaper than the virgin ones. Despite of these environmental and economic strengths, the use of recycled sources is still low compared to the raw materials consumption, in fact in Europe only 10% of the market is covered by recycled products. One of the reasons of this reticence in the use of secondary sources is the lack of an accurate quality certification system. The feed of a recycled process is not always the same, which means that also the corresponding output can vary depending on the initial composition of the treated material. Usually, if a continuous quality control system is not present at the end of the process, the quality of the output material is assessed on the minimum certified characteristics. Solving this issue is crucial to expand the possible applications of recycled materials and to assign a price based on the real characteristics of the product.

In this paper the possibility to apply a quality control system, based on an hyperspectral imaging (HSI) working in the near infrared (NIR) range, to the separation process of PVC cable wastes is explored. The analyzed material was a residue fraction of a traditional separation process further treated by magnetic density separation. Results show as PVC, PE, rubber and copper particles can be identified and classified adopting the NIR-HSI approach.

9486-37, Session PTue

Endmember signature based detection of flammable gases in LWIR hyperspectral images

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Segmentation and identification of compounds or materials existing in a scene is a crucial process. Hyperspectral sensors operating in different regions of the electromagnetic spectrum are able to quantify spectral characteristics of materials in different states. Due to the fact that some chemical compounds in gas state have insignificant light reflectance characteristics as compared to solids and liquids in visible region of the spectrum, imaging sensors operating in infrared regions are needed to sense energy absorbance or transmittance characteristics of these compositions. The present study proposes a novel method for detection of flammable gases in long-wave infrared hyperspectral images. Proposed method begins with a series of pre-processing steps, including blackbody radiation curve compensation and dimensionality reduction. Since a priori information regarding the compounds in the scene is not always available, endmember spectral signatures are extracted with N-FINDR and VCA hyperspectral unmixing approaches. Afterwards, endmember signatures are matched with infrared energy absorbance signatures of gases obtained from NIST (National Institute of Standards and Technology) Material Measurement Laboratory. Finally, concentration of target signature at each image pixel is detected by means of endmember abundance maps. The performance of the approach is compared with that of similarity measure based gas detection methods. It is observed that the proposed technique removes the need for an external threshold setting while providing better resolvability of the gasses.

9486-38, Session PTue

On-chip surface enhanced Raman spectroscopy (SERS)-linked immuno-sensor assay (SLISA) for rapid and global environmental surveillance of chemical-toxins

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The increasing threat of an intentional (attack) or accidental release of toxins, in particular, chemical-toxins, including chemical warfare agents (CWAs) and toxic industrial chemicals (TICs), has increased public fear. The major problem in such attacks/accidents is to detect toxins present in very low levels. Indeed, several detection techniques are currently being used for the same. However, none of them meet the most demanding requirements of a detect-to-protect class of biosensors, which is a critical need of federal agencies, including the Department of Homeland Security, Department of Defense and Environmental Protection Agency (EPA).

Our group has developed a prototype lab-on-a-chip (LOC) using silver-based-surface-enhanced Raman spectroscopy (SERS)-linked immuno-sensor assay (SLISA). The LOC-SLISA was tested for the measurement of a stress-marker protein, RAD54, expressed by yeast in response to hydrogen-peroxide (H_2O_2), a toxin in the EPA priority list of chemical-toxins. This design, for the detection of stress-marker protein in response to toxin (response to dose effect), allows detection of known as well as unknown toxins (global sensing), which can be correlated to human-health using information available on EPA databases. We found, the SLISA has good correlation in accuracy with the standard ELISA technique, and outperforms the latter by being rapid and easy-to-use. SLISA has an edge over ELISA, SLISA is 5 times more sensitive, provides qualitative information on sensor characterization and immuno-assay, and allows direct detection with minimal/no chances of uncertainty, a concern in label-based biosensing technologies. The results were correlated to EPA's defined exposure guideline levels of H_2O_2 to validate the significance of our quick, easy, cheap, effective, robust and safe (QuEChERS), detect-to-protect biosensor for environmental surveillance.

9486-39, Session PTue

Ring resonators in polymer foils for sensing of gaseous species

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Micro ring resonators manufactured with well established silicon-nitride wafer technology and functionalized by coating with receptor molecules, are already being used successfully for sensitive and selective detection; e.g. with receptors based on triphenylene ketals, the explosive TNT could be detected down to concentrations of 300 ppt [1].

In this paper, the concept of a micro ring resonator formed of waveguides in tailor-made polymers is presented. Extensive simulations were performed to determine appropriate dimensions for the waveguide and the design of ring and coupling zone as well as for the estimation of losses. The main contributions are diffraction losses due to bending of the waveguide and losses due to the roughness of the waveguide walls. Based on the calculated parameters, a first polymer ring resonator was realized using microscope projection lithography. Selectivity is only ensured by use of appropriate receptor coatings. Therefore, different receptor molecules were synthesized to address CO and CO_2.

Results of the characterization of the ring resonator and its sensing performance will be discussed.

The project is part of the German collaborative research centre "Planar Optronic Systems" (Sonderforschungsbereich, Transregio 123) funded by the DFG. The aim is to realize a sensor network in a large-scale polymer film with integrated and distributed optical sensors to measure variables such as pressure, temperature, different fluids as well as gases.

[1] R. Orghici, P. Lützow, J. Burgmeier, J. Koch, H. Heidrich, W. Schade, N. Welschoff und S.R. Waldvogel. A microring resonator sensor for sensitive detection of 1,3,5- trinitrotoluene (TNT). Sensors, 10, 6788-6795, (2010)

9486-40, Session PTue

New possibility to analyse non-standard explosives and post blast residues in forensic practice

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Electron microscopy - SEM, EDS/WDS is one of the key techniques for an analysis of non-standard explosives and post blast residues. If the amount of material allows, a number of other analytical techniques are used such as XRD that is capable of a direct phase identification of a crystalline substance, namely in mixtures. TLC has constantly proved itself for laboratory screening, furthermore, combinations of FTIR, Raman spectrometry, LC MS, GC MS, XRF, micro XRF and other ones are applied. In the case of identification of post-blast residues where an examination is often carried out at the level of separate microscopic particles, the role of SEM is unsubstitutable, whereas the analysis of the organic phase from these often sporadic microparticles has been until recently infeasible. One of the very interesting options appears to be the Raman spectrometry technique, which is nowadays available as a supplement to SEM EDX. Newly available is the device that is fully confocal, SEM keeps full functionality and scan range, very high resolution (for green laser resolution 360nm FWHD; 430nm Rayleigh), it is fitted with high quality objective lens, allows mapping through Raman spectrometry in a volume 250μm x 250μm x 250μm by piezo driven scanner (capacitive feedback linearized) and obtaining high quality white light image (250μm x 250μm) immediately in the SEM chamber. This technique is currently undergoing intensive testing and it seems that the method could significantly help to solve problems with the analysis of organic phases in electron microscopy not only in the case of post-blast residues and explosives.

Conference 9487: Smart Biomedical and Physiological Sensor Technology XII

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9487-1, Session 1

Smartphone based paper/plastic hybrid microfluidic chemiluminescence sensor for nanomolar peroxide detection

Renny E. Fernandez, Elise Lebiga, Southern Methodist Univ. (United States); Mayank Ahuja, Plano East Senior High School (United States); Alexander Lippert, Ali Beskok, Southern Methodist Univ. (United States)

We report a chemiluminescence sensor system for detection and quantification of nanomolar levels of hydrogen peroxide (H202) using a hybrid paper/plastic disposable device incorporated to a smart phone (iPhone). The hybrid microfluidic device consists of a paper reaction pad and plastic microchannels. The reagents are delivered to the paper pad through plastic microfluidic channels, while the chemiluminescence, due to the reaction of Bis (2,4,6-trichlorophenyl) oxalate with H202 in the presence of rubrene and Imidazole, is confined to the paper reaction pad. The photon emission analysis of the reaction is quantified by integrating the intensity profile extracted through image processing of the Full HD 1080p videos recorded at 30 fps with 8 megapixel inbuilt iPhone camera. H202, the rate limiting analyte, is quantified using the decay curve of the chemiluminescence reaction carried out under pseudo first order conditions. The hybrid microfluidic device is specifically designed to confine the whole chemiluminescent reaction to paper pads with definite dimensions (radius: 3 mm; A: 28 mm2). The sensor system was found to be sensitive to H202 concentrations as low as 250 nM with respect to the control.The custom designed Hybrid paper/plastic (low cost) microfluidic system is suitably incorporated to a smartphone using a mini enclosure for rapid video capture and analysis. The results obtained were verified using an inverted research microscope configured with a CMOS digital camera.

9487-2, Session 1

Microsystem integrated immunosensor for the detection of the bioterrorist agent francisella tularensis

Ciara K. O'Sullivan, Ioanis Katakis, Univ. Rovira i Virgili (Spain)

Tularemia is a highly infectious zoonotic disease caused by a Gram-negative coccoid rod bacterium, Francisella tularensis. Tularemia can be treated with antibiotics, but it is still considered as a life-threatening potential biological warfare agent due to its high virulence, transmission, mortality and simplicity of cultivation. In the work reported here, different electrochemical immunosensor formats for the detection of whole F.tularensis bacteria were developed and their performance compared. An anti-Francisella antibody (FB11) was used for the detection that recognises the lipopolysaccharide found in the outer membrane of the bacteria. In the first approach, gold-supported self-assembled monolayers of a carboxyl terminated bipodal alkanethiol were used to covalently cross-link with the FB11 antibody. In an alternative second approach F(ab) fragments of the FB11 antibody were generated and directly chemisorbed onto the gold electrode surface. The second approach resulted in an increased capture efficiency and higher sensitivity. Detection limits of 4.5 ng/mL for the lipopolysaccharide antigen and 31 bacteria/mL for the F.tularensis bacteria were achieved. Having demonstrated the functionality of the immunosensor, an electrode array was functionalised with the antibody fragment and integrated with microfluidics and housed in a tester set-up that facilitated complete automation of the assay. The only end-user intervention is sample addition, requiring less than one-minute hands-on time. The use of the automated microfluidic set-up not only required much lower reagent volumes but also the required incubation time was considerably reduced and a notable increase of 3-fold in assay sensitivity was achieved with a total assay time from sample addition to read-out of less than 20 min.

9487-3, Session 1

Sensor enhanced microfluidic devices for cell based assays and organs on chip

Claudia Gärtner, Holger Becker, Ingo Schulz, Tobias Jahn, Cäcilia Freund, microfluidic ChipShop GmbH (Germany)

Cell based assays and organ-like substrates gather an increasing attention due to their potentials in diagnostic and drug development. The use of these cell-based systems will allow to better understand in vivo processes and test for the direct influence of different substances e.g. in drug development and in addition to identify the influence of generated metabolites or different cell types.

To enable the use of these biological tools, a respective technical platform was realized based on microfluidic systems. The microfluidic elements are designed in a fashion allowing not only for cell culture on chip but also for the targeted reagent and nutrition supply. Furthermore the influence of the metabolism from one cell type on the other can be evaluated due to the arrangement of cell compartments as interacting networks. Elements being essential for this work include membrane elements for the separation of liquid stream together with a targeted supply of reagents and a three dimensional feeding of embedded cells. Fluidic networks facilitate minimize manual steps and a respective microfluidic cell culture incubator will be introduced allowing for a direct manipulation on a microscope stage and an incubator free cell culture.

Material choice and surface functionalization are further topics being essential for the implementation of the cell base-assays on chip.

Sensor systems embedded in the microfluidic system for pH, CO2 and temperature, monitor the on-chip conditions and enable defined assay conditions.

The respective microfluidic cell assay toolbox will be presented as well as examples for implemented assays on chip ranging from cell culture showing the cell behaviour in respect to material, surface functionalization and different growth conditions to finally embedding organ-on-chip structures of cultured and co-cultured cell lines.

9487-4, Session 1

Integrated microsystem for multiplexed genosensor detection of biowarfare agents

Samuel Dulay, Univ. Rovira i Virgili (Spain); Rainer Gransee, Fraunhofer ICT-IMM (Germany); Sandra Julich, Herbert Tomaso, Friedrich-Loeffler-Institut (Germany); Ciara K. O'Sullivan, Univ. Rovira i Virgili (Spain) and Institució Catalana de Recerca i Estudis Avançats (Spain); Ioanis Katakis, Univ. Rovira i Virgili (Spain)

An early, rapid and definite detection for the presence of biowarfare agents, pathogens, viruses and toxins is required in different situations which include civil rescue and security units, homeland security, military operations, public transportation securities such as airports, metro and railway stations due to its harmful effect to human population. In this work, an electrochemical genosensor array that allows simultaneous detection of different biowarfare agents with integrated microsystem that provides

an easy handling of the technology which combines with microtube fluidics setup has been developed and optimised for the following specific genoassay: Bacillus anthracis, Brucella melitensis, Bacteriophage lambda, Francisella tularensis, Burkholderia mallei, Coxiella burnetii, Yersinia pestis, and Bacillus thuringiensis var. kurstaki. The chip electrodes arrays were modified via co-immobilisation of a 1:100 (mol/mol) mixture of a thiolated probe and a polyethyleneglycol-terminated bipodal thiol. PCR products from these relevant biowarfare agents were detected reproducibly through a sandwich assay format with the target hybridised between a surface immobilised probe into the electrode and a horseradish peroxidase-labelled secondary reporter probe, which provided an enzyme based electrochemical signal. The potential of the designed microsystem for multiplexed genosensor detection and cross-reactivity studies over potential interfering DNA sequences has demonstrated high selectivity using the developed platform producing high-throughput.

9487-5, Session 1

Ultrafast real-time PCR with integrated melting curve analysis and duplex capacities using a low-cost polymer lab-on-a-chip system

Rainer Gransee, Fraunhofer ICT-IMM (Germany); Tristan Schneider, Univ. of Applied Sciences Wiesbaden (Germany); Deniz Elyorgun, Fachhochschule Bingen (Germany); Tobias Schunck, Christian Winkler, Julian Hoeth, Xenia Strobach, Theresia Gatscha, Fraunhofer ICT-IMM (Germany)

Nucleic amplification has become the gold standard of molecular testing. Real-time or quantitative (qPCR) systems offer both DNA amplification and simultaneous fluorescence detection. 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] allowing the amplification of native genomic deoxyribonucleic acid (DNA) molecules. This abstract presents the actual status of the renewed and advanced system. The system generates high quality quantitative PCR amplification plots and additional sensitive melting point analysis comparable to data obtained from commercial real-time cyclers. These features provide the user with all information needed to analyze the PCR products. 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. 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. The integration of duplex amplification performance allows the incorporation of the necessary controls into the device to validate the PCR performance. This demonstrator can be run either as fully autonomously working device or as OEM part of a sample-to-answer platform.

[1] Fast nucleic acid amplification for integration in point-of-care applications, Electrophoresis 2012, 33, 3222–3228

9487-6, Session 2

Biocompatible membrane coated electrochemical aptamer-based sensors for long-term monitoring in complex sample matrices

Lauren R. Schoukroun-Barnes, Ethan Glaser, Ryan J. White, Univ. of Maryland, Baltimore County (United States)

To compatibly interface with a biological system, the sensor must not be fouled by the nonspecific adsorption of proteins and thus lose sensitivity. As such, compatible interfacing with biological systems means less sample pretreatment of the system being investigated, which allows the researcher to investigate the system in native, typically complex, environments. Unfortunately, many biosensors often fail when challenged in complex biological matrices (e.g., serum, blood, cytoplasm and cerebral spinal fluid), as a result of nonspecific adsorption of proteins and/or degradation of the recognition element.

A sensor platform that exhibits promising detection abilities in complex sample matrices is the electrochemical, aptamer-based (E-AB) sensor. These sensors utilize aptamers as specific recognition elements. Aptamers are single-stranded DNAs or RNAs that are produced in vitro to bind a specific target. In order to use these aptamers for E-AB sensors, the 5'-electrode bound aptamer must undergo a specific conformation change upon binding to the target analyte. By attaching methylene blue (a redox active molecule) to the distal end of the aptamer this conformation change can be monitored electrochemically. Because of this specific and selective signaling ability, E-AB sensors achieve detection directly in untreated serum. However, this detection is made on the seconds time scale, and the sensors fail when employed for longer time scales (minutes-hours). In this talk, I will discuss how we adhere a biocompatible hydrogel membrane to E-AB sensor surface to mitigate fouling of the sensor and enable long-term, real-time detection directly in whole blood.

9487-7, Session 2

Rapid Detection of Listeria spp. using an Internalin A Aptasensor Based on Carbon-metal Nanohybrid Structures

Diana C. Vanegas-Gamboa, Univ. of Florida (United States) and Univ. del Valle (Colombia); Yue Rong, Neil Schwalb, Univ. of Florida (United States); Katherine D. Hills, Carmen L. Gomes, Texas A&M Univ. (United States); Eric S. McLamore, Univ. of Florida (United States)

Foodborne outbreaks caused by Listeria monocytogenes continue to raise major public health concerns worldwide. In the United States alone, the centers for disease control and prevention have confirmed the occurrence of 183 cases of listeriosis with 39 fatalities within the last 3 years. Standard methods for the detection of pathogenic strains require up to 7 days to yield results, thus faster techniques with the same level of reliability for bacteria detection are desirable. This study reports on the development of a rapid, accurate, and sensitive electrochemical biosensor for rapid testing of Listeria spp. based on the selective binding of InlA aptamers to internalins in the cell membrane of the target bacteria. Hybrid nanomaterial platforms based on reduced graphene oxide and nanoplatinum were deposited onto Pt/Ir electrodes for enhancing electrochemical transduction . InlA aptamers were immobilized onto the nanomaterial platforms via metal-thiol self-assembly. Aptamer loading onto different platform nanostructures was investigated through cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS). The detection mechanism was evaluated by recording the electrochemical response to several bacterial dilutions in PBS buffer using the non-pathogenic species Listeria innocua. Preliminary data have shown that the aptasensor can be tuned for detection of listeria concentrations as low as 100 CFU/ml in less than 3 hours (including incubation time), although these numbers are expected to improve with further studies. The developed aptasensor is a promising approach for rapid testing of Listeria monocytogenes in food analysis.

9487-8, Session 2

Electrochemical detection of francisella tularensis genomic DNA using solid-phase recombinase polymerase amplification

Ciara K. O'Sullivan, Ioanis Katakis, Univ. Rovira i Virgili (Spain)

Solid-phase isothermal DNA amplification was performed exploiting the homology protein recombinase A (recA). The system was primarily tested on maleimide activated microtitre plates as a proof-of-concept and later translated to an electrochemical platform. In both cases, forward primer for Francisella tularensis holarctica genomic DNA was surface immobilised via a thiol or an amino moiety and then elongated during the recA mediated amplification, carried out in the presence of specific target sequence and reverse primers. The formation of the subsequent surface tethered amplicons was either colorimetrically or electrochemically monitored using a horseradish peroxidase (HRP)-labelled DNA secondary probe complementary to the elongated strand. The amplification time was optimised to amplify even low amounts of DNA copies in less than an hour at a constant temperature of 37 ºC, achieving a limit of detection of 1.3·10-13 M (4·106 copies in 50 ?L) for the colorimetric assay and 3.3·10-14 M (2·105 copies in 10 ?L) for the chronoamperometric assay. The system was demonstrated to be highly specific with negligible cross-reactivity with non-complementary targets or primers.

9487-9, Session 2

ECL detection of francisella tularensis DNA target based on “switch-on-off” strategy with surface confinement of the system using diazonium salt as a molecular linker

Mabel Torrens, Mayreli Ortiz, Ciara K. O’Sullivan, Ioanis Katakis, Univ. Rovira i Virgili (Spain)

In the present work, using ECL, a sensor for detecting a DNA target related with Francicella tularensis was developed. The Francisella subspecies holarctica and tularensis are the causative agent of the disease tularemia, because of the ingestion of contaminated food, water supplies, and contact with rabbits or hares infected. Nowadays the detection of F. tularensis involves culturing suspect pathogens which is a time consuming technique. Detection of antibodies can also be used for diagnosis but the drawback is that antibodies are not detected until two weeks after the infection. An alternative for the early detection of subspecies holarctica and tularensis is the use of the specific sequences of fopA or tul4od. Thus, to reduce the health impact of this hazardous pathogen, biosensors to detect specific DNA sequences from Francisella tularensis have been studied. Herein, taking this DNA sequence as a model target, an “on-off” approach was developed based on a type sandwich detection of DNA by using two partially complementary DNA sequences with almost consecutive regions of the DNA target: a capture DNA probe labeled with the luminophore ruthenium (II) trisbipyridine N-hydroxysuccinimide (Rubpy), which produces light and a secondary DNA probe labeled with the ferrocene able to quench the luminescence. The close proximity of the Rubpy to ferrocene permits the energy transferring and the subsequent quenching effect of the ferrocene over the former, which is not possible in the absence of DNA target. The study was carried out in solution and by confinement the system on the electrode surface using a recently reported diazonium salt platform as a linker.

9487-10, Session 2

Electrochemiluminescence genosensor for multiplex detection of pathogen species

Ciara K. O’Sullivan, Ioanis Katakis, Univ. Rovira i Virgili (Spain)

In this contribution we describe development of a sensor for multiplex detection of pathogens by their DNA using ECL detection. ECL is a highly sensitive method where light is generated at the surface of an electrode upon application of potential. One of the most potent luminophores used is ruthenium trisbipyridine (Ru(bpy)3 2+), which has been used in assay for detection of DNA and proteins over three decades, ever since the first demonstration by Blackburn et al in 1991. ECL has been demonstrated applicable for detection of DNA on gold electrodes (Miao and Bard 2003, Spehar-Délèze et al. 2006). Firrao (2005) has demonstrated the ECL detection of DNA hybrid immobilised directly on glassy carbon electrode via C-N bond between the electrode carbon molecule and amine group from aminated oligonucleotide formed by application of high potential. Different methods for DNA immobilisation and electrode surface treatments are evaluated for ECL detection.

9487-11, Session 3

Dynamic analysis and performance evaluation of the BIAcore surface plasmon resonance biosensor

Juan F. Ospina, Univ. EAFIT (Colombia)

Solution procedures were proposed to analyze nonlinear mass transport through an optical biosensor. A generalized collocation technique was applied to predict the dynamic behavior of an analyte along the flow chamber as a result of convection, diffusion and chemical reaction. The method estimated the effective time constants for reaching average steady-state concentrations of the free and bound analytes in the cell. When diffusion in the direction of flow was neglected, a closed-form solution, based on double Laplace transforms, was obtained after linearizing the original system. In both models, an increase in the sample diffusion coefficient lowered the effective time constant. This approach may help researchers evaluate the performance of biosensors and meet specific design criteria.

9487-12, Session 3

Implementation of a novel fiber optic Fourier transform infrared (FO-FTIR) spectroscopy approach for non-contact and label-free sensing of biochemical contamination

Moinuddin Hassan, Elizabeth Gonzalez, Victoria M. Hitchins, Ilko K. Ilev, U.S. Food and Drug Administration (United States)

Healthcare associated infections (HAI) in clinics and hospitals are a major concern to public health and impose significant medical, social and economic consequences. Approximately 1 in every 20 inpatients develops an HAI. Reusable medical devices (RMDs), while being used to diagnose, prevent disease, monitor, treat patients, or sustain life, can serve as a reservoir of infectious agents as they repeatedly come into contact with multiple patients and healthcare professionals. Therefore, it is vital that RMDs are properly cleaned and disinfected/sterilized between uses. When reprocessing RMDs, they must first be properly cleaned before disinfected or sterilized to ensure that the device is exposed to the disinfectant/sterilant. However, currently there are few options for healthcare workers to verify the success of the cleaning process. Current techniques are based on ex-situ approaches such as swab/wipe sampling, which are time consuming, can introduce low recovery efficiency, and do not monitor and detect pathogen contamination in real time. In order to reduce HAIs from reusable devices, alternative methods for quantitative, accurate, easy-to-use and real-time detection and identification of microorganism contaminations on medical devices surfaces in clinical setting are needed. We have recently presented a novel proof-of-concept platform for non-contact, label-free and real-time detection of medical device surface contamination employing a fiber-optic Fourier Transform Infrared (FO-FTIR) spectroscopy methodology in the mid-infrared spectral range of 2.5um to 12um. In this study, we demonstrate the detection sensitivity of FO-FTIR sensing for four species of bacteria: Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa and Streptococcus pneumoniae. Initially, bacteria samples containing approximately 10^9 CFU/mL were prepared and then, serially diluted up to

eight times. Preliminary study showed that the FO-FTIR based sensor can detect the presence of the bacteria at concentrations between 10^3 and 10^4 CFU/2uL. This sensing method combined with a multivariate analysis may potentially be used as effective pathogen screening tool for routine monitoring in clinical setting.

9487-13, Session 3

Process patent protection: protecting biopharmaceutical intellectual property via natural-abundance stable isotopes

(Invited Paper)

John P. Jasper, Nature's Fingerprint (United States) and Molecular Isotope Technologies, LLC (United States)

The ambient distribution of light stable isotopes in biopharmaceutical synthetic pathways permits the identification and differentiation of potentially-infringing pathways. After reviewing three cases of product identification, we examine three cases of process authentication, protecting $1.5 billion in biopharmaceutical products: one of false advertising and two of process patent infringement. The three cases of product authentication demonstrate the dynamic range of the light stable isotopes in differentiating sources of pharmaceutical materials. The false-advertising case was substantially a product case because the green-tea L-Theanine and the client- and competitor L-Theanine were markedly different in carbon- (~15‰) and nitrogen isotopic (~10‰) composition. The competitor L-Theanine process was revealed from court documents and chemical-isotopic insight. The competitor was accused of falsely advertising the source of their L-Theanine. The second case of process patent infringement was a straightforward case of infringement. An infringer used synthetic intermediates that were readily available on the market to produce the infringing product. When confronted with the isotopic evidence of process infringement, an out-of-court, business resolution was reached. The third case of process infringement was a case of wrongful accusation of infringement. The carbon-isotopic records of both the product and process studies show that (i) the products are of different origins and (ii) the defendant had in fact used a different synthetic pathway so that he was not infringing the patent of the plaintiff.

Possible Addendum: Online process analysis of natural-abundance stable isotopes affords a marked opportunity to monitor bioreactors and chemical-production systems in real time. Advances in theory and in technology over the last decade plausibly afford the opportunity for online monitoring of the state of such systems. I will review the development of a Stable Isotopic Indirect Calorimeter (http://www.naturesfingerprint.com/abstracts/abstract_i10272000.shtml) as an example of a bioreactor / gas purifier / offline isotope-analytical system which could readily be converted to an online system. Next, I will briefly review the contemporary stage of online isotope-ratio monitored, continuous reactors.

9487-14, Session 3

Remote characterization of biological specimens using all-optical frequency-domain photoacoustic microscopy

Ashwin Sampathkumar, Riverside Research Institute (United States)

Photoacoustic (PA) imaging (PAI) and characterization (PAC) of biological specimens using pulsed lasers have been widely demonstrated. For microscopy applications, the high cost and long scan times of such systems limit the scope of PAI or PAC of thin biological specimens. In this paper, we describe a narrow-bandwidth generation and detection of PA signals in biological specimens using frequency-domain photoacoustics. An intensity-modulated laser operating at 632 nm with a peak power of 100 mW was used for PA generation, and an interferometer coupled to a 200-MHz, radio frequency lock-in amplifier was used for detection. The amplitude and phase of the PA signal was measured at the modulation frequency as the frequency was swept over the bandwidth of interest. Enhancement in detection sensitivity was achieved by sinusoidal modulation of the excitation laser over long time scales. The transient PA response of the sample to a synthesized pulse was reconstructed from the frequency-domain data. These signals were then used to recreate a map of the optical absorbers in the specimen using time-reversal methods. Experimental results obtained from 500-?m graphite rods embedded in tissue-mimicking phantoms and slide-mounted tissue samples will be presented along with time-domain and time-reversal reconstruction maps. We believe that the frequency-domain photoacoustics is ideally suited for rapid interrogation of thin biological samples, with higher incident power density and signal-to-noise ratio compared to pulsed laser systems.

9487-15, Session 3

3D noninvasive, high-resolution imaging using a novel photoacoustic tomography system (pat) and rapid wavelength-cycling lasers

Ashwin Sampathkumar, Riverside Research Institute (United States); Marc Klosner, Gary Chan, Chunbai Wu, Donald F. Heller, Light Age, Inc. (United States)

Breast cancer ranks second as a cause of cancer death in women (after lung cancer). Recently, death rates for breast cancer have steadily decreased in women due to progress in earlier detection and improved treatment modalities. While there are a host of applications for PAT technology, breast imaging for the purpose of cancer screening and diagnosis is one of considerable importance, affecting both cost and quality of healthcare provided to patients nationally and globally. For mammography, a distinction between malignant and benign tumors may be made by categorizing the morphologies of the vascular support structures. Additional discrimination can be achieved by exploiting the differential absorption between oxy- (HbO2) and deoxy-hemoglobin (Hb) at 755 nm and (near the isosbestic point) at 797 nm or at longer wavelengths, where relative absorptions of HbO2 and Hb reverse. More specifically, since malignant tumors have lower levels of oxygenation and greater blood volume compared with non-malignant tumors, Multispectral PAT can often be performed by capturing separate images at 755 nm to predict the oxygenation level, augmented by images at 797 nm to characterize total blood volume. Current tunable laser systems offer access to hemoglobin-specific operational wavelengths at the expense of high cost, low power and longer pulse-repetition frequency (PRF). In this work, we describe the development of a PAT system using a rapid wavelength-cycling Alexandrite laser designed for clinical photoacoustic imaging (PAI) applications. The laser features high-pulse-energy output at clinically relevant repetition rates, as well as a novel wavelength-cycling output pulse format. It provides 500 mJ/pulse at 755 and 797 nm for a pulse-width of 50-70 ns and a PRF of 25-50 Hz. Wavelength cycling provides a pulse sequence for which the output wavelength repeatedly alternates between 755 nm and 797 nm rapidly within milliseconds. This capability enables improved co-registration of images captured at the different wavelengths of operation. We present imaging results of breast phantoms with inclusions, obtained with this laser source and a custom-built 2-MHz, 20-element transducer ring that is adapted to a 128-element Verasonics system. The results include photoacoustic images and oxygen saturation maps of tubular (50-250 ?m) and spherical structures (1-5 mm), mimicking blood vessels and tumors in the breast.

9487-21, Session 3

Bridgman growth of lead selenoiodide for multifunctional detectors

David House, Reecha Suri, Christopher Cooper, Brad

Arnold, Fow-Sen Choa, Lisa Kelly, Univ. of Maryland, Baltimore County (United States); Liliana Braescu, Institut National de la Recherche Scientifique (Canada); Narsingh B. Singh, Univ. of Maryland, Baltimore County (United States)

There is a strong need for the HOT MWIR detectors for a variety of imagers This paper describes a novel material to fulfill this gap.

9487-38, Session 3

Advancing innovative regulatory science and public health through CDx: FDA's development of a counterfeit detection tool

Leigh Verbois, Nicola Ranieri, U.S. Food and Drug Administration (United States)

To minimize consumer and patient exposure to counterfeit products scientists at the FDA's Forensic Chemistry Center in Cincinnati, Ohio developed a tool, the CDx, Counterfeit Detection Device, to rapidly screen products. The CDx is a handheld, battery-operated tool that illuminates a product with a variety of wavelengths of light to provide a visual comparison of an unverified product with an authentic sample. The first version tool has been in use since 2005 in their laboratory. The third version of the tool (CD3) has been in use since 2010 in a number of international mail facilities in the United States and other points of entry where investigators screen drug ingredients and other finished products to identify counterfeit or unapproved products. CDx has also been applied effectively to screen cosmetics, foods, medical devices, and cigarettes, and investigate product tampering and questionable documents. This allows users to identify suspect products and remove them from the supply chain. Additionally, minimal scientific or technical background is needed to operate the tool, and it can be used even in remote communities or in places with only very basic health care systems. As the Agency made continued improvements to CDx, it has engaged in efforts to maximize the public health benefit of CDx (CD3+ is the current version). These have included (1) the development of a testing strategy which evaluates the technological capabilities and potential deployment strategies, (2) developing a path for device optimization and production of devices for testing and (3) development of a deployment strategy. The concurrent development of strategic partnerships is necessary to undertake testing, optimization, and manufacturing, and to understand the broader deployment of CDx. These concurrent efforts are in recognition that the Agency has immediate need for production as well as acknowledges the potential public health impact of CDx if distributed to a wider audience.

9487-33, Session PThu

Speckle-correlation imaging through highly scattering turbid media with LED illumination

Xiaopeng Shao, Weijia Dai, Tengfei Wu, Huijuan Li, Lin Wang, Xidian Univ. (China)

We address an optical imaging method that allows imaging, which owing to the "memory-effect" for speckle correlations, through highly scattering turbid media with compressed sensing (CS) theory. When light propagates the opaque materials, such as white paint or human tissues, it will be scattered away due to the inhomogeneity of the refractive index. Multiple scattering of light in highly scattering media forms speckle field, which will greatly reduce the imaging depth and degrade the imaging quality. Some methods have been developed to solve this problem in recent years, including wavefront modulation method (WMM), transmission matrix method (TMM) and speckle correlation method (SCM). A novel approach is proposed to image through a highly scattering turbid medium, which combines SCM with phase retrieval algorithm based on compressed sensing (CS) theory. Its remarkable advantages are embodied in that it can decrease the imaging time due to the fact that CS uses the structure information of a signal, which can sample less data than the requirement of Nyquist sampling theory. Simultaneously, instead of the demand for the support area, the phase retrieval algorithm based on the CS uses an -norm as the constraint. Theoretical and experimental results show that, neither coherent source, nor wave-front shaping is required in this method, and that the imaging can be easily realized here using just a simple optical system with the help of optical memory effect. And large amounts of speckle data and the choice of a suitable support area limit its application, which are solved by this method. Consequently, it will be beneficial to achieve imaging in currently inaccessible scenarios.

9487-34, Session PThu

Imaging through turbid media via sparse representation: imaging quality comparison of three projection matrices

Xiaopeng Shao, Huijuan Li, Tengfei Wu, Weijia Dai, Lin Wang, Xidian Univ. (China); Xiangli Bi, School of Optoelectronics, Beijing Institute of Technology (China) and Science and Technology on Electro-Optical Information Security Control Laboratory (China)

The incident light will be scattered away due to the inhomogeneity of the refractive index in many materials, such as tissues, which will greatly reduce the imaging depth and degrade the imaging quality. Many exciting methods have been presented in recent years for solving this problem and realizing imaging through a highly scattering medium, such as the wavefront modulation technique, speckle correlation and so on. The imaging method based on compressed sensing (CS) theory which proposed recently can decrease the computational complexity because it doesn't require the whole speckle pattern to realize reconstruction. One of the key premises of this method is that the object is sparse or can be sparse representation. However, choosing a proper projection matrix is very important to the imaging quality. In this paper, by utilizing the knowledge of statistics, we analyzed that the transmission matrix of a scattering medium obeys circular Gaussian distribution, which makes it possible that a scattering medium can be used as the measurement matrix in the CS theory. In order to verify the performance of this method, a whole optical system is simulated, in which the Rayleigh-Sommerfeld diffraction is employed to describe the light propagation between optical devices. Various projection matrices are introduced to make the object sparse, including the Fourier transform basis, the wavelet transform basis and the discrete cosine transform basis, the imaging performances of each of which are compared comprehensively. Simulation results show that the choice of optimal projection matrix varies with the type of observed targets, and for most targets, applying the wavelet transform basis will obtain an image in good quality. This work can be applied to biomedical imaging and used to develop real-time imaging through highly scattering media.

9487-35, Session PThu

A spectral method of color modeling and calibration for optical imaging systems

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A method was elaborately designed to modeling the color information of optical imaging systems, by which the color calibration could be implemented among different optical imaging systems by adjusting the digital inputs of their captured images. In this process, a monochromator was employed to generate monochromatic light with 20 nm interval in the

visible spectrum. Afterwards, the radiance of each monochromatic light could be measured by a spectroradiometer, and the spectral response curve of the sensor in the optical imaging system could be derived accordingly by the mapping algorithms between these physical measurements and the recorded digital inputs of images, which was a significant feature for representing color information. Meanwhile, the tristimulus values of GretagMacbeth color checker under a given lighting condition were measured by the spectroradiometer, by which the color mapping models were established by polynomial expressions for individual optical imaging systems, capable of making conversions between the tristimulus values of an arbitrary color and its corresponding digital inputs in the captured image. Therefrom, based on the spectral response features of the sensor and the proposed color mapping models, the color calibration would be actualized among different optical imaging systems by a two-step image manipulation algorithm, containing the forward conversion and the inverse conversion in color mapping between two optical imaging systems. From the spectral aspect, the proposed procedure and algorithms provided instructive solutions on the color modeling and calibration among different optical imaging systems, which were capable to supply the same color information in their captured images on the same scene, equivalent to implementing color management.

9487-36, Session PThu

Leptospirosis risk depending on the distance to a potential source of infection

Erica Tatiana E. Loaiza Echeverri, Doracelly D. Hincapie-Palacio, Jesus J. Ochoa, Univ. de Antioquia (Colombia); Juan F. Ospina, Univ. EAFIT (Colombia)

Leptospirosis is bacterial zoonosis with world distribution and multiform clinical spectrum in humans and animals. The etiology of this disease is the pathogenic species of the Leptospira type. In this paper, diverse manifestations of the disease, from mild to severe, such as the Weil disease and the lung hemorrhagic syndrome with lethal proportions of 10% - 50% are described. This is an emerging problem of urban health due to the growth of marginal neighborhoods that lack basic sanitary conditions, which at the same time has favored the increased number of rodents. The presence of rodents and the possibility of having contact with their urine determine the likelihood for humans to get infected. In this paper, we estimate how the risk of human infection depending on the proximity to the rodent burrows is modified. We simulated the spatial distribution of risk infection around a potential source of rodents that expel leptospira through their urine. We did this by using the Bessel function K(0), with an r distance from the observation spot to the source, and the scale parameter ? in meters. We used the published data of the leptospirosis incidence rate (rank of 5 to 79 x 10 000), and a distance of 100 to 5000 meters from the source of infection. We obtained an adequate adjustment between the function and the simulated data. The risk of infection increases with the proximity of the potential source. This estimation can become a guide to propose effective measures of control and prevention.

9487-16, Session 4

Flexible SERS-based substrates: challenges and opportunities toward an Army relevant universal sensing platform *(Invited Paper)*

Mikella E. Farrell, U.S. Army Research Lab. (United States); Srikanth Singamaneni, Washington Univ. in St. Louis (United States); Paul M. Pellegrino, U.S. Army Research Lab. (United States)

Generally the fabrication, assembly and evaluation of plasmonic nanostructures for surface enhanced Raman scattering (SERS) substrates has focused on static rigid substrates such as glass and silicon. However, these static substrates severely limit the application of plasmonic nanostructures as (i) they provide no means to alter the state of assembly of the nanostructures once they are formed or anchored on the surface i.e., not reconfigurable and (ii) preclude applications which demand non-planar, flexible or conformal surfaces. The above considerations has led to the development of a novel class of SERS substrates based on flexible substrates such paper, polymer membranes and electrospun fibers. These flexible SERS media based on unconventional substrates such as paper offer distinct advantages compared to the conventional SERS substrates in that (i) flexible nature of the substrate enables conformal contact with the surfaces under investigation leading to efficient sample collection; (ii) porous nature of the SERS substrate (interstices between the fibers) provides efficient access to the analytes; (iii) high surface area of the 3D paper substrate results in large dynamic range of the chemical sensors; (iv) intricate network of fibers decorated with metal nanoparticles can provide potentially high density of electromagnetic hotspots and (v) intense light scattering caused by the fibrous structure of the substrate (e.g., paper) enables efficient light-metal interaction; (vi) facile fabrication leads to efficient, robust, reliable, reusable and cost- effective SERS substrates. In this presentation, we will focus on the Army need for a more flexible (substrate surface and application) SERS substrate for universal sensing. This presentation will leverage off a previous flexible SERS (May 2014) workshop hosted by Dr. Srikanth Singamaneni at Washington University.

9487-17, Session 4

Surface-enhanced Raman scattering from living cells: from differentiating healthy and cancerous cell to cytotoxicity assessment *(Invited Paper)*

Mustafa Culha, Gamze Kuku, Melike Saricam, Sevda Mert, Yeditepe Univ. (Turkey)

There is an ongoing effort to obtained molecular level information from living cells using surface-enhanced Raman scattering (SERS) not only to understand changes of cellular processes upon exposure to external stimuli but also decide the status of cells whether they are healthy or abnormal. In our research effort, we investigate how much information can be obtained from living cells to use for decision making about the cellular processes. The undertaken studies include differentiation of the healthy and cancer cells and cytotoxicity assessment of the nanomaterials.

9487-18, Session 4

Quantitative detection and SERS

Amanda J. Haes, The Univ. of Iowa (United States)

Directly detecting low concentrations of small molecules in biological and environmental samples is often limited by similar molecular structures and function of the target species as well as complex sample matrices. When nanoparticles are used to facilitate detection, an additional limitation of signal irreproducibility from changing surface functionality further complicates both qualitative and quantitative detection. Often, biological recognition elements in these sensors are composed of antibodies, functional groups, nucleic acids, etc. Because surface recognition layers can exhibit variability as a function of temperature, matrix, shelf life, and pH; surface chemistry and quality control measures that promote both nanomaterial stability and responsiveness are vital and motivate our investigations. Herein, the design of stable yet responsive optically-active nanostructures for the detection of biologically-relevant metabolites in a high throughput, sensitive, and selective manner thereby combating current dynamic detection limitations will be discussed. Localized surface plasmon resonance (LSPR) spectroscopy, normal Raman spectroscopy (NRS), and surface enhanced Raman scattering (SERS) will be discussed for applications in the direct, qualitative and quantitative detection of small biologically and environmentally relevant molecules. In particular, chemical reactions of various small molecule environmental contaminants

will be detected and speciation assigned based on vibrational frequency assignments. Metal nanoparticles will be shown to provide enhancement. Upon comparison speciation in solution vs. on the SERS substrates, a better understanding will result. These results are expected to provide important information regarding the mechanism of small molecule detection using SERS. In the future, these results could be expanded for different nanomaterials cores, molecular targets, and sensor-based detection platforms.

9487-19, Session 4

Functionalized paper SERS (P-SERS) substrates for selective targeting of analytes in complex samples

Wei W. Yu, Eric P. Hoppmann, Diagnostic anSERS, Inc. (United States)

Inkjet-printed paper SERS (P-SERS) substrates were recently introduced by Diagnostic anSERS, Inc. as an inexpensive alternative to micro-fabricated SERS substrates. These highly sensitive paper SERS substrates eliminate the high costs associated with traditional SERS sensing approaches and have been demonstrated in a wide variety of applications, including food contaminants, pesticides and illicit drugs. Unlike conventional SERS substrates, flexible P-SERS substrates are simple to use and possess additional ability to separate analytes from a complex mixture (via paper chromatography) and analyte re-concentration (via lateral flow). P-SERS substrates enable SERS to become a field-applicable technique.

Despite these advances, P-SERS, like other existing SERS substrates, rely on the affinity of the analyte to the nanostructure surface for enhancement. This limits the application of SERS to molecules that possess functional groups that interact strongly with gold or silver surfaces, such amines and thiols. To enable P-SERS substrates to be more applicable for a wider range of analytes, we report in this work the functionalization of P-SERS substrates by strategically placing various linking groups onto the gold nanoparticles to promote the selective interaction of target molecules with the plasmonic surface. We will present data to show that the presence of these linking groups on the nanoparticle surface allow for the specific capture of target analytes from complex samples and lead to improved SERS performance.

9487-20, Session 4

Large area super-resolution chemical imaging via rapid dithering of a nanoprobe

Eric R. Languirand, Brian M. Cullum, Univ. of Maryland, Baltimore County (United States)

Super-resolution chemical imaging via Raman spectroscopy offers chemical specificity, affording the ability to multiplex numerous label-free analytes while elucidating the spatial distribution on the surface of the sample. However, spontaneous Raman is an inherently weak phenomenon making trace detection and thus super-resolution imaging extremely difficult, if not impossible. To circumvent this and allow for a trace detection of the few species present in each sub-diffraction limited area, we have developed a surface enhanced Raman scattering (SERS) coherent fiber-optic imaging bundle probe consisting of 30,000 individual fiber elements. When the probes are tapered, etched and coated with metal, they provide circular Raman chemical images with a field of view of 20μm in diameter via the array of 50 nm individual fiber elements. An acousto-optic tunable filter is used to rapidly scan or select discrete frequencies for multi- or hyperspectral analysis.

Although the 50nm fiber element dimensions of this probe inherently provide spatial resolutions of approximately 100nm, further increases in the spatial resolution can be achieved by using a rapid, 2-step dithering process. Using this process, two additional images are obtained one-half fiber diameter translations in the x- and y- planes. A piezostage drives the movement, allowing accurate and reproducible shifts required for dithering. These images are then deconvoluted from each other to increase the spatial resolution three-fold. This talk will describe super-resolution chemical imaging using these probes and the dithering method as well as its applications in label-free imaging of lipid rafts and other applications within biology and forensics.

9487-22, Session 5

Characterization of the role of oxide spacers in multilayer-enhanced SERS probes

Pietro Strobbia, Brian M. Cullum, Univ. of Maryland, Baltimore County (United States)

Surface enhanced Raman spectroscopy (SERS) has several advantages as a transduction method for many types of optical sensors, due to its sensitivity and potential multiplex detection. Over the years, SERS probes have been developed to be capable of extreme sensitivities, with single molecule SERS having been achieved in randomly located hot-spots of colloidal aggregates. However, these structures suffer from significant irreproducibility, due to the randomness of the aggregation. Alternatively, strategies such as ordered 2D arrays or enhancement based on single probes (e.g. immuno-nanosensors, nanostars) have high reproducibilities but limited enhancement factors.

A widely applicable enhancing geometry, developed in our laboratory, based on metal thin films interleaved with dielectric spacers takes advantage of interaction into the volume of the probe (perpendicularly to the surface) to enhance the signal independently from the underlying structure.

Preliminary evidence into the mechanism of this enhancement suggests that the dielectric spacer material and thickness play a key role in the magnitude of the resulting additional enhancement. In this paper we investigate the material dependence of the multilayer enhancement using substrates fabricated using ultrathin oxide spacer layers deposited by atomic layer deposition. The SERS enhancement measured for substrates based on semiconductor and dielectric materials have been characterized in order to understand which properties influence the multilayer enhancement the greatest. In addition a model to describe the mechanism by which the spacer properties influence the multilayer enhancement will also be discussed.

9487-23, Session 5

Optical nanosystems for biomolecular reaction studies *(Invited Paper)*

Jing Pan, Tae-Gon Cha, 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.

9487-24, Session 5

From materials science to next generation sensing using synthetic and engineered peptide technology *(Invited Paper)*

Dimitra N. Stratis-Cullum, U.S. Army Research Lab. (United States)

Natural biological systems exhibit the exquisite ability to spatially combine many weak, non-covalent chemical interactions to direct the molecular recognition and self-assembly of incredibly complex materials. The ability to control assembly at the molecular level has led to an interest in harnessing nature's building blocks (e.g., polypeptides) to tailor interaction with both biological and inorganic materials for a variety of applications. By using biocombinatorial approaches it is possible to first create biochemical diversity, and then mimic natural selection through artificial "biopanning" methods. The discovery and evolution of peptide candidates with the desired interaction can be tuned for selective interaction with the target material. In this paper, we will review and highlight two powerful biocombinatorial methods, bacterial cell-surface display and protein catalyzed capture reagents (PCC). We have shown that it is possible to use these methods to enable selective and specific interaction, thereby enabling high performance synthetic antibody substitutes, as well as hybrid material systems. This paper will include highlights of our most recent work showing record thermostability with retention of target interaction after extended exposure to extreme environmental conditions (e.g.,70C-90C), as well as progress towards the development of genetically engineered peptides for inorganics (GEPI) and autonomous cell templating capabilities.

9487-25, Session 5

Enhancing enzymatic efficiency by attachment to semiconductor nanoparticles for biosensor applications *(Invited Paper)*

Joyce C. Breger, Scott Walper, Eunkeu Oh, Kimihiro Susumy, Michael H. Stewart, Jeffrey Deschamps, Mario G. Ancona, Igor L. Medintz, U.S. Naval Research Lab. (United States)

Nanosensors employing quantum dots (QDs) with appended biofunctional moieties offer tremendous promise for disease surveillance/diagnostics and chemical/biological threat activity. Their small size permits cell penetration and their inherent photochemical properties are well-suited for rapid, optical measurement. The effectiveness of enzymes immobilized on QDs, however, are not completely understood, hindering development of chemical/biological sensors and remediation materials. Here, we analyze enzyme effectiveness for the neutralization of a simulant nerve agent when attached to two distinctly sized QDs. Two sizes of QDs, 525 or 625 nm, were appended with DHLA ligands to improve aqueous stability and prevent aggregation. Various molar ratios of phosphotriesterase (PTE) were rapidly self-assembled via spontaneous metal coordination of the PTE oligiohistidine tag onto the Zn^{2+}-rich QD surface. PTE catalyzes the detoxification of organophosphate pesticides (e.g, paraoxon, an analog of sarin) to p-nitrophenol whose absorbance can be measured at 405 nm. The optimal ratio of PTE to 525 nm and 625 nm QD's was determined to be 6 and 8, respectively. At these ratios, we saw a ~50-60% increase in Vmax for PTE along with improvement in other kinetic parameters. The influence of solution viscosity and a competitive inhibitor were also studied to determine their effect on kinetic processes. The enhanced enzyme performance in both cases is most likely due to increased enzyme-substrate interactions from improvements in enzyme orientation, enzyme density, and substrate diffusion on or near the QD. Development of these nansosensors as optical-based biosensors (e.g., within compact microfluidic devices) may greatly improve the sensitivity of conventional biological/chemical detection schemes.

9487-26, Session 5

Structural reconfiguration of DNA origami *(Invited Paper)*

Haorong Chen, Feiran Li, Jong Hyun Choi, Purdue Univ. (United States)

DNA origami represents a class of highly programmable macromolecules that can go through conformational changes in response to external signals. Here, we show that a two-dimensional (2D) origami rectangle can be effectively folded into a short, cylindrical tube by connecting the two opposite edges through the hybridization of linker strands and that such process can be efficiently reversed via toehold-mediated strand displacement. The reconfiguration kinetics is experimentally studied as a function of incubation temperature, initial origami concentration, missing staples (i.e. structural defects), and origami geometry. A simple kinetic model is developed by introducing j-factor to describe the reaction rates in the cyclization process. We find that the cyclization efficiency (j-factor) increases sharply with temperature and depends strongly on structural flexibility and geometry. A simple mechanical model correlates the observed cyclization efficiency with origami structure details. The mechanical analysis suggests two sources of energy barrier for DNA origami folding: overcoming global twisting and bending the structure into circular conformation. It also provides the first semi-quantitative estimation of the rigidity of DNA inter-helix crossovers, an essential element in structural DNA nanotechnology. This work demonstrates efficient DNA origami reconfiguration, advances our understanding of the dynamics and mechanical properties of DNA structures, and should be valuable to the field of DNA nanotechnology.

9487-27, Session 6

Automated calculation of bifurcation carotid angle for analyzing the risk of carotis plaques by using carotid ct angiographic images

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The aim of this study is calculation of bifurcation carotid angle by detection of vein boundaries to answer if this angle is a risk factor about formation of carotis plaques.

The carotid artery is the large vertical artery in the neck. The carotid artery starts at the arch of the aorta . The carotid artery divides into the internal carotid artery and the external carotid artery. The internal carotid artery supplies the brain. Plaque often builds up at that division, and causes a narrowing (stenosis). Pieces of plaque can break off and block the small arteries above in the brain, which causes a stroke.

Carotid ct angiography images are clustered automatically by ISODATA unsupervised classification algorithm. Since the spectral digital numbers(DN) of vein pixels are bigger than the other part of the images, the cluster which has the biggest median value of DN among all other classes gives the vein class.

The cluster image in raster format is converted into the vector format which allows to work on the vein geometry. The converted vector vein cluster data-set has been simplified using Douglas-Peucker algorithm to eliminate the zigzag effects of pixel data which are remained on the vector form data-set. Then the cluster polygon is converted to lines and the vertices which will be used for the calculation of bifurcation carotid angle.

For sorting the vertex points to calculate the angle on each vertex, alpha-shapes algorithm is applied along the boundary. Then all the angles on each vertex point along the boundary of veins are calculated. It is also visually clear that the angle which has the minimum value among all the calculated angles, gives the bifurcation carotid angle. The calculated angle values will be analyzed by one of the authors regarding formation of carotis plaques. 5 sample data-sets are used to test the method, and will be extended to ca.50 samples. The calculated angle values of 5 samples are 68.24, 17.90, 48.19, 25.57, 29.84 degrees respectively.

9487-28, Session 6

Electroencephalograph (EEG) Study of Brain Bistable Illusion

Qinglei Meng, Univ. of Maryland, Baltimore County (United States); Elliot Hong, Univ. of Maryland, Baltimore (United States) and Univ. of Maryland School of Medicine (United States); Fow-Sen Choa, Univ. of Maryland, Baltimore County (United States)

Bistable illusion reflects two different kinds of comprehension for one certain image, which is now known as a competition between two groups of antagonism of neurons. Recent research indicates that these two groups of antagonism of neurons express different comprehension, while one group is emitting a pulse, the other group will be restrained. On the other hand, when this inhibition mechanism becomes weaker, the other antagonism neurons group will replace this function. Since attention play key roles controlling cognition, is highly interesting to find the location and frequency band used in brain (with either top-down or bottom-up control) to reach deterministic visual perceptions. In our study, we used a 16-channel EEG system to record brain signals from subjects while conducting bistable illusion testing. An extra channel of the EEG system was used for time marker. The moment when subjects reach a perception switch, they click the channel and generate a spiking time marker. The recorded data were presented in form of brain electrical activity map (BEAM) with different frequency bands for analysis. It was found that the visual cortex on the right side between parietal and occipital areas was controlling the switching of perception. Compared with a period of stable perception, during which all delta, theta, alpha and beta wave band distribution could be observed, while illusion was switching, theta, alpha and beta waves were all mostly suppressed by delta waves. This indicated that delta wave may control the processing of perception switching.

9487-29, Session 6

Sensor probes and phantoms for advanced transcranial magnetic stimulation system developments

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Transcranial magnetic stimulation (TMS) has become one of the most widely used noninvasive method for brain tissue stimulation and has been used as a treatment tool for various neurological and psychiatric disorders including migraine, stroke, Parkinson's disease, dystonia, tinnitus and depression. In the process of developing advanced TMS deep brain stimulation tools, we need first to develop field measurement devices like sensory probes and brain phantoms, which can be used to calibrate the TMS systems. Currently there are commercially available DC magnetic or electric filed measurement sensors, but there is no instrument to measure transient fields. In our study, we used a commercial figure-8 shaped TMS coil to generate transient magnetic field and followed induced field and current. The coil was driven by power amplified signal from a pulse generator with tunable pulse rate, amplitude, and duration. In order to obtain a 3D plot of induced vector electric field, many types of probes were designed to detect single component of electric-field vectors along x, y and z axis in the space around TMS coil. We found that resistor probes has an optimized signal-to-noise ratio (SNR) near 3k ohm but it signal output is too weak compared with other techniques. We also found that inductor probes can have very high output for Curl E measurement, but it is not the E-field distribution we are interested in. Probes with electrical wire wrapped around iron coil can directly measure induced E-field with high sensitivity, which matched computer simulation results.

9487-30, Session 6

A very low-cost 3D scanning system for whole-body imaging

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

A low-cost, high resolution 3D scanning system has been developed by faculty and students at the University of North Dakota. This hardware creates 3D models (complete with color and texture data) using hardware and software with a cost of approximately $5,000. These models can be easily manipulated in computer aided design (CAD) software to allow assessment, customization or the creation of derivative (e.g., fitted clothing) objects. The scanner is based on a collection of networked Raspberry Pi units with 5 megapixel cameras and uses visible light scanning and point cloud-based 3D model reconstruction. With 50 Raspberry Pi units, the system utilizes over 250 megapixels of data to generate the model and color/texture data. The Raspberry Pi units collect this data concurrently with a total scan time of approximately two seconds.

This paper provides an overview of the design, testing and initial uses for this scanning hardware. The structural framework that was designed for supporting and positioning the cameras is discussed. Also presented, are a number of alternate configurations that were considered (and not utilized) which may be more suitable for certain applications. The paper also discusses the efficacy of this technology for a variety of applications (including medical, sporting, garment/hazardous condition suit development and artistic). It considers the utility of being able to capture high-quality scans at low cost in terms of what applications could be enabled by increasing access to 3D scanning technology. A discussion of the required operating conditions and the limitations that this places on the applications the scanner is suitable for is also included. The paper concludes with a discussion of the efficacy of 3D scanning technology for enabling numerous applications and the role of visible light and low-cost visible light solutions, like the scanner discussed, in enabling these applications.

9487-32, Session 6

Mathematical modeling of Chikungunya fever control

Juan F. Ospina, Univ. EAFIT (Colombia)

Chikungunya fever is a global concern due to the occurrence of large outbreaks, the presence of persistent arthropathy and its rapid expansion throughout various continents. Globalization and climate change have contributed to the expansion of the geographical areas where mosquitoes Aedes aegypti and Aedes albopictus remain. It is necessary to improve the techniques of vector control in the presence of large outbreaks, in American Continent. We derive measures of disease control, using a mathematical model of mosquito-human interaction, by means of three scenarios: a) a single vector b) two vectors, c) two vectors and human and non-human reservoirs. The basic reproductive number and critical control measures were deduced by using computer algebra with Maple 11 (Maplesoft Inc, Ontario Canada). Control measures were simulated with parameter values obtained from published data. According to the number of houses in high risk areas, the goals of effective vector control to reduce the likelihood of mosquito-human transmission would be established. Besides the two vectors, if presence of other non-human reservoirs were reported, the monthly target of effective elimination of the vector would be approximately double compared to the presence of a single vector. The model shows the need to periodically evaluate the effectiveness of vector control measures.

9487-37, Session 6

Printing graphene-based inks on flexible substrates for biosensor applications

Jonathan C. Claussen, Iowa State Univ. (United States)

Printed electronics developed with ink jet printing technology have becoming increasingly attractive for a variety of reasons including low cost, scalability, and the ability to print on a wide variety of surfaces such as paper and polymers that typically degrade during photolithographic processing. Furthermore, ink-jet printed graphene electronics also inherently incorporate the unique material properties of graphene (e.g., high conductivity, flexibility, strength, and biocompatibility) that make them well suited for a variety of applications including supercapacitors, thin film transistors, and biosensors. In this work we developed an exfoliated graphene ink for printable biosensors. The graphene ink is printed onto a flexible substrate, i.e., Kapton tape, along with silver/silver chloride ink and carbon ink to create a printed 3-electrode circuit for amperometric, electrochemical sensing. An enzymatic layer consisting of the enzyme lactate oxidase is immobilized on the working electrode (printed graphene) for subsequent lactate sensing—a biomarker associated with muscle fatigue found within the sweat. The sensitivity of the printed circuit to lactate is analyzed as well as the durability of the biosensor during flexed and un-flexed scenarios. These results demonstrate the potential of graphene-printed electronics in epidermal biosensor applications.

Conference 9488: Sensing for Agriculture and Food Quality and Safety VII

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9488-1, Session 1

Magnetostrictive particles used for biosensors for the detection of pathogen in liquid and their potential as a novel actuator *(Invited Paper)*

Kewei Zhang, Taiyuan Univ. of Science and Technology (China); ZhongYang Cheng, Auburn Univ. (United States)

Magnetostrictive particles (MSPs) have been developed as the sensor platform for the development of high-performance biosensors due to its high sensitivity and wireless nature. The MSP-based biosensors work well in liquid making it is suitable for in-situ detection of pathogenic bacteria in liquid. In this study, both phages against S. typhimurium and antibodies against L. monocytogenes, E. coli and S. aureus were used as the bio-probe (i.e. biomolecular recognition unit) that is immobilized onto the surface of MSPs that have a size of 1.0 mm x 0.3 mm x 15 ?m. These biosensors were characterized in pathogenic bacteria cultures with different populations ranging from 5x101 to 5x108 cfu/ml. It is found that these biosensors have rapid response (a response in minutes). Therefore, these biosensors are suitable for in-situ and real-time detection of pathogenic bacteria in liquid. The experimental results show that all the MSP-phage and MSP-antibody biosensors exhibit a detection limit better than 100 cfu/ml. When the cultures with population <106 cfu/ml are tested, both MSP-phage and MSP-antibody sensors exhibit the similar response. However, the phage-MSP sensors exhibit a higher capability in the capture of target bacterial cell. Additionally, it is found that the MSP-based sensors can move in space using an ac magnetic field with a specific frequency and that the motion direction is controlled by the frequency of the ac magnetic field. The physics behind this phenomenon is discussed.

9488-2, Session 1

High throughput pathogen screening for food safety using magnetoelastic biosensors *(Invited Paper)*

Suiqiong Li, Soochow Univ. (China); Bryan A. Chin, Auburn Univ. (United States)

In order to secure food safety, high throughput pathogen screening technique that can quickly identify and isolate unsafe contaminated food has been long-desired. Recently, magnetoelastic (ME) free-standing biosensors have been investigated as a label-free wireless biosensor system for real-time pathogen detection. ME biosensor is composed of a ME resonator coated with a bio-molecular recognition element that binds specifically with a target pathogen. Once the biosensor comes into contact with the target pathogen, binding occurs, resulting in a decrease of the sensor's resonant frequency. Interrogated through magnetic signals, large amount of ME sensors can be deployed and monitored wirelessly. ME biosensors have been investigated to detect foodborne pathogens in cultures and liquid foods. Recently, it has been demonstrated that phage-based ME biosensors are able to directly detect Salmonella Typhimurium in food products without the requirement of pre-analysis culture preparation. This presentation will present the novel ME biosensor technique, including the detection principle, the interrogation system, the fabrication of ME biosensors and their applications, especially for food safety analysis. Direct detections of foodborne pathogens on food products with different surface morphologies, such as tomato, spinach and egg surface, have been demonstrated. The detection limit up to 10^2 CFU/cm^2 has been obtained using phage-coated ME biosensors with the size of 1 x 0.2 x 0.028 mm. The ME biosensor technique has the potential to be a powerful screening tool by monitoring food contamination, in real-time along the entire food supply chain.

9488-3, Session 1

Detection of heavy metals with graphene-based biosensors

Nick Wu, West Virginia Univ. (United States)

Heavy metals are pollutants that exist in the surface water, soils and food, which poses threat to food safety and human health. Fluorescent biosensors have been developed for detection of heavy metals. However, organic dyes are used in conventional fluorescent biosensors. Organic dyes are vulnerable to photobleaching. In this work, reduced graphene oxide (rGO) has been used as a substitute of organic dye to construct fluorescent biosensors. rGO is coupled to a fluorophore to enable a resonance energy transfer processes, in which rGO acts as an energy acceptor. Alternatively, rGO can be used as an energy donor, that is, a fluorophore. This work has demonstrated different types of fluorescent biosensors using rGO as either an energy donor or an acceptor. Such biosensors show high sensitivity and selectivity toward detection of heavy metals.

9488-4, Session 1

In-situ detection of multiple pathogenic bacteria on food surfaces

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Real-time in-situ detection of pathogenic bacteria on fresh food surfaces was accomplished with phage-based magnetoelastic (ME) biosensors. The ME biosensor is constructed of a small rectangular strip of ME material that is coated with a biomolecular recognition element (phage, antibodies or proteins, etc.) that is specific to the target pathogen. This mass-sensitive ME biosensor is wirelessly actuated into mechanical resonance by an externally applied time-varying magnetic field. When the biosensor binds with target bacteria, the mass of the sensor increases, resulting in a decrease in the sensor's resonant frequency. In order to compensate for nonspecific binding, control biosensors without phage were used in this experiment. In previous research, the biosensors were measured one by one. However, the simultaneous measurement of multiple sensors was accomplished in this research, and promises to greatly shorten the analysis time for bacterial detection. Additionally, the use of multiple biosensors enables the possibility of simultaneous detection of different pathogenic bacteria. This paper presents results of experiments in which multiple phage-based ME biosensors were simultaneously monitored. The E2 phage and JRB7 phage from a landscape phage library served as the bio-recognition element that have the capability of binding specifically with Salmonella Typhimurium and B. anthracis spores, respectively. Real-time in-situ detection of Salmonella Typhimurium and B. anthracis spores on food surfaces are presented for various pathogen concentrations.

9488-5, Session 1

Application of a LED-based reflectance sensor for the assessing in situ the lycopene content of tomatoes (Lycopersicon esculentum Mill.)

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Non-destructive in situ determination of the antioxidant lycopene of fresh tomato fruits is of large interest for the growers, willing to optimize the harvest time for high quality products. For this, we developed a new LED-based sensor able to measure directional reflectance spectra of whole tomatoes in the 400-700 nm range. As comparison, total reflectance spectra of the same fruits were also recorded by using an integrated sphere connected to a bench spectrophotometer. The tomato skins from the very same samples were then frozen in liquid nitrogen, extracted with an acetone/ethanol/hexane mixture and spectrophotometrically analyzed for their lycopene content. Concentration of lycopene was varying between 0.07 and 0.55 mg/g fresh weight skin. Partial Least Squares Regression (PLSR) was used to correlate spectral data to the tomato lycopene content. The PLSR analysis of directional reflectance showed that lycopene content could be nicely predicted with a coefficient of determination R2=0.945 and a root mean square error of cross-validation RMSECV=0.057 mg/g. Similar results were obtained for the PLSR analysis of total reflectance data R2=0850, and RMSECV=0.044 mg/g. Our results suggest that portable, low-cost and compact LED-based sensors appear to be promising instruments for the non-destructive assessment of tomato lycopene even in the field.

9488-6, Session 1

Detection of salmonella of globe fruits using pulse excited magnetoelastic biosensors

Howard C. Wikle III, Songtao Du, Bryan A. Chin, Auburn Univ. (United States)

This paper describes the results of a research project to investigate magnetoelastic (ME) biosensors actuated with a pulse excitation to measure the concentration of Salmonella Typhimurium of globe fruits. The ME biosensors are based on an acoustic wave resonator platform that is a freestanding (free-free) thin ribbon of magnetostrictive material with a length-to-width ratio of 5:1. A biorecognition probe coated on the surface of the resonator platform binds with a targeted pathogen, i.e. E2 phage that binds with S. Typhimurium. The biosensor was actuated to vibrate longitudinally such that the resonant frequency depended primarily on the length of sensor and its overall mass. A pulsed excitation and measurement system was used to actuate micron scale ME biosensors to vibrate. The biosensor responds in a ring-down manner, a damped decay of the resonance amplitude, from which the resonant frequency was measured. An increase in mass due to the binding of the target pathogen resulted in a decrease in the resonant frequency. The mass of the captured Salmonella was determined from the difference in the vibration frequency before and after exposure to the pathogen. The pulsed excitation and measurement system that was developed under this effort and the characterization of its performance on the measurement of Salmonella concentrations on globe fruits is described.

9488-7, Session 2

Bioenabled nanophotonic sensors for food safety and drinking water monitoring

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Inspired by advanced nanofabrication techniques, rationally designed optical sensors have gained tremendous research interest in recent years. Although unprecedented sensitivity, repeatability and specificity have been achieved, many of these rationally designed optical sensors are manufactured using cost-prohibitive, top-down nanofabrication techniques, which are not feasible for frequent spot inspection of food safety and drinking water monitoring. Diatoms are photosynthetic micro-organisms that create their own skeletal shells of hydrated amorphous silica, called frustules, which naturally possess hierarchical micro- & nano-scale features that are extremely cumbersome and expensive to duplicate by top-down fabrication techniques. These diatom nanostructures are readily and cheaply obtained by cultivation of diatom cells, followed by isolation of the diatom frustules through conventional chemical separation techniques. In this paper, we report that a hybrid biological-plasmonic nanostructure, i.e. the diatom frustule and the self-assembled nanoparticles, can obtain label-free surface-enhanced Raman scattering (SERS) sensing with ultra-high sensitivity. The ultra-high sensitivity of the bioenabled nanophotonic sensors comes from the coupling between the diatom frustules and Ag nanoparticles to achieve dramatically increased local optical field to enhance the light-matter interactions for surface-enhanced Raman scattering (SERS) sensing. We successfully applied the bioenabled nano-photonic sensors to detect melamine in milk and aromatic compounds in water with sensitivity down to 1?g/L. We also proved that the bioenabled nanophotonic sensors can be used with commercially available portable Raman spectrometers, which will provide a cost-effective in-situ sensing technique for food safety and drinking water monitoring.

9488-8, Session 2

Optimization of phage-based magnetoelastic biosensor to detect salmonella on bird feces contaminated leafy green vegetables

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The outbreak of foodborne diseases caused by bacteria, such as O157:H7 E. coli and Salmonella has become a great concern in food safety[1]. The consumption of foodborne bacteria contaminated vegetables is one of the causes of foodborne disease. Vegetables can be contaminated by animal manure, for example, bird feces. Bird feces contain Salmonella which is a pathogen that lives in the intestines of the infected birds and is shed through feces. Bird could fly over or land on leafy green vegetables, such as spinach, iceberg lettuce and cabbage, leading to the potential bird feces contamination. Recently, USFDA found that the outbreak of Salmonella in peanut butter may be linked to the exposure of bird feces to the raw, unshelled peanuts that were stored outdoors where birds were observed flying over and landing on the in-shell peanuts[2]. Even though water washing can remove feces and reduce bacterial contamination, it is still difficult to eliminate bacteria at all. Therefore, detection Salmonella in bird feces contaminated leafy green vegetables is required. The phage-based magnetoelastic biosensor has been developed to detect Salmonella on food surface [3, 4]. In the present work, we optimized the current phage-based magnetoelastic biosensors to detect Salmonella on bird feces contaminated vegetables. Several parameters influencing the effectiveness of detection were optimized, such as, incubation time and blocking agent concentration. A protocol was developed to visualize Salmonella on biosensor surface to correlate the resonance frequency measurement of biosensors. Our detection protocol could contribute to screening the leafy green vegetables after harvesting to reduce effort and cost.

9488-9, Session 2

Electronic nose fabricated from nanocomposite oxides for agriculture applications

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Off-odor detection in foods, packaging materials, and their interactions involving scalping or other flavor system modification can be a serious issue since off-odors or flavors have become more than a quality issue with the increased awareness of food safety problems. Since plants and trees normally release volatile organic compounds (VOCs) as a byproduct of everyday physiological processes, monitoring of the specific VOCs and the quantities released can provide the information on both the crop and field conditions. The electronic nose generally consists of an array of gas sensors with a broad and partly overlapping selectivity and an electronic pattern recognition system with multivariate statistical data processing tools. In this study, a microfabricated electronic nose system is investigated to hybrid nanostructured metal oxide based on ZnO, SnOx and graphene oxide, and their composite film segmented by a series of electrodes to create a high density of sensing array in a small size chip. The novelty of the proposed microarray is based on the formation of a composite structure by spatially gradient composition and/or microstructure through sensing layers where each wire-type electrode induces its unique response pattern. Such a design can meet the requirements for low-cost and high-volume production in combination with high gas analytical performance. The results on the growth of the nanostructured films using solution process are presented. Sensing properties of the devices are also discussed in terms of sensitivity, selectivity and response rate.

9488-11, Session 2

A biosensor based on magnetic resonance relaxation

MariAnne Sullivan, Barton C. Prorok, Auburn Univ. (United States)

Conventional culture and susceptibility tests continue to remain the “gold standard” for identifying pathogens in clinical and other settings. Many new pathogen detection approaches have aimed at replacing this standard by providing more rapid, more accurate and less expensive detection. Very promising techniques such as PCR, surface enhanced Raman, and others have proven adept at pathogen detection, but end users have not warmed up to their expense, extensive sample preparation and skill set necessary to perform them. The field continues to search for a rapid, sensitive, and specific detection technology that is cost-effective and easy to use. This work describes a biosensor based on magnetic resonance relaxation switching. The method leverages a large body of work involving nanoscale contrast agents employed in nuclear magnetic resonance (NMR) imaging. The aim was to develop a detection approach that mimics the human immune response to an invading pathogen, the release of 109 to 1012 specific antigens to guarantee quick contact with the pathogen. The technique employs magnetic nanoparticle contrast agents conjugated with specific capture agents to achieve a similar contact goal. Detection of the species involves monitoring the average relaxation time (T2) of water protons in the solution, which is highly sensitive to the concentration and distribution of the magnetic nanoparticles present. With multiple nanoparticles attaching to each individual target species their distribution will be altered, and correspondingly, the average proton relaxation time will change. Although, this method leverages well established principles of NMR imaging, this measurement can be accomplished with a simple hand-held relaxometer. This detection technique appears to have the potential to mitigate 4 of the primary factors limiting the effectiveness of current detection strategies: (1) poor contact statistics between the sensor platform and target – which impacts detection time, (2) sample preparation – which is required to concentrate or remove pathogens from the sample and/or remove or reduce interferents, (3) non-specific binding – which significantly reduces sensitivity and selectivity of the detection method, and (4) ease and cost of use – most end users will not have PhDs or a high level of training. Our results have identified an ideal concentration of magnetic nanoparticles that imparts the highest sensitivity to changes in particle distribution. We have also discovered that increasing the concentration of particles actually reduces the sensitivity of the technique by as much as a two orders of magnitude

9488-12, Session 2

Nature-inspired magnetoelastic biosentinels for the detection of pathogenic bacteria in stagnant liquids

Shin Horikawa, Yating Chai, Howard C. Wikle III, Jing Dai, Jiajia Hu, Auburn Univ. (United States); Sang-Jin Suh, Auburn Univ (United States); Bryan A. Chin, Auburn Univ. (United States)

This paper presents an investigation into magnetoelastic (ME) biosentinels that seek out, capture, and detect target pathogens in stagnant liquids. The biosentinels are designed to mimic a variety of white blood cell types, the main defensive mechanism in the human body against different pathogenic invaders. These nature-inspired biosentinels are composed of an ME resonator coated with a landscape phage that binds specifically with the pathogen of interest. When subjected to an externally applied time-varying magnetic field, the biosentinels can be placed into mechanical resonance (i.e., bending or longitudinal mode of vibration) by magnetostriction. The resonating biosentinels can then move autonomously through a liquid due to the net acting force and fluid-structure interactions. As soon as the biosentinels find and bind with the target pathogens, changes in the mass as well as resonant frequency of the biosentinels occur, and thereby the presence of the target pathogen can be detected. The resonance frequency changes were measured wirelessly with a designed electromagnetic coil connected to a network analyzer that operates in the reflection mode. As an initial model study, detection of Bacillus anthracis spores (Stern strain), a Category A bioterrorism agent, under stagnant flow conditions was investigated. This investigation will advance the fundamental scientific theories describing the operation of biosentinels and have broad societal impact by improving human health through earlier detection of pathogens. Potential short-term applications include the capture and detection of pathogenic bacteria in liquid food products such as juices and milk.

9488-10, Session PTue

The blocking reagent optimization for the magnetoelastic biosensor

Jiajia Hu, Changzhou Univ. (China) and Auburn Univ. (United States); Yating Chai, Shin Horikawa, Auburn Univ. (United States); Howard C. Wikle, Auburn University (United States); Feng’en Wang, Institute of Quality Standard & Testing Technology for Agro-products, Shandong Academy of Agricultur (China); Songtao Du, Auburn University (United States); Bryan A. Chin, Auburn Univ. (United States); Jing Hu, Changzhou Univ. (China)

Wireless phage-based magnetoelastic (ME) biosensors have proven to be promising for real-time detection of pathogenic bacteria on fresh produce. These biosensors consist of a freestanding ME resonator as the signal transducer and engineered phage as the biomolecular-recognition element that binds specifically with the pathogen of interest. Due to the

Joule magnetostriction effect, the biosensors can be placed into mechanical resonance when subjected to a time-varying magnetic field alternating at the right frequency. Upon the attachment of the target pathogen, the mass of the biosensor increases, thereby decreasing its resonant frequency. This paper presents results from an investigation to detect Salmonella typhimurium mixed with feces on apple surface using phage-based ME biosensors. The Salmonella typhimurium detection was conducted using a surface-scanning coil detector by wirelessly monitoring changes in the resonant frequency of the biosensors in real time (up to 30 min) in a humid environment. The frequency shift was conducted by a surface-scanning coil detector, and the surface image after Salmonella typhimurium binding was observed by optical microscope and Scanning electron microscopy (SEM). The results showed that the frequency shifts are closely related to the concentration of Salmonella typhimurium and feces, and the surface images confirmed the binding of Salmonella typhimurium, and thus resulting in the frequency shifts. This work demonstrates the detection of live bacteria on fresh produce.

9488-26, Session PTue

Rapid detection of foodborne pathogens in pork meat by surface-enhanced Raman scattering

Feifei Tao, Yankun Peng, China Agricultural Univ. (China)

Microbial hazard is one of the major challenges to meat safety, and rapid identification and detection methods for foodborne pathogens are urgently needed in meat industry at present. The objectives of this study were to explore the capabilities of surface-enhanced Raman scattering (SERS) for rapid identification and quantification of foodborne pathogens in pork meat. The SERS signals of Escherichia coli (E. coli) and Staphylococcus aureus (S. aureus) were obtained respectively on novel gold nanoparticle covered SiO2 substrates excited at 785 nm by the lab set-up Raman spectral system, over the Raman shift between 400 and 2000 cm-1. The spectral preprocessing methods of fluorescence background removal and Savitzky-Golay smoothing were conducted on their original SERS signals, and the Raman fingerprints were determined for E. coli and S. aureus respectively. In this study, pork meat samples with different loads of E. coli and S. aureus were artificially prepared, and three groups of pork meat samples contaminated by E. coli, S. aureus and the mixture of E. coli and S. aureus respectively were used for SERS spectra acquisition and reference microbiological analyses. The determined Raman fingerprints of E. coli and S. aureus from their respective suspensions were further used to analyze the bacterial contamination in pork meat samples. Soft Independent Modeling of Class Analogies (SIMCA) and Partial Least Squares Regression (PLSR) methods were performed to identify the contaminated bacteria types, and quantify the corresponding bacteria numbers in pork meat samples respectively. Based on SERS technique and the gold nanoparticles applied, the detecting limits of E. coli and S. aureus were also discussed in this study. The obtained results shown in this article demonstrate that SERS has great potentials for rapid identification and quantification of foodborne pathogens in pork meat, and hopefully to become a powerful tool for rapid detection of foodborne pathogens in meat industry.

9488-27, Session PTue

Research on identification and determination of mixed pesticides in apples using surface enhanced Raman spectroscopy

Chen Zhai, Yongyu Li, Yankun Peng, Tianfeng Xu, Sagar Dhakal, China Agricultural Univ. (China); Kuanglin Chao, Jianwei Qin, USDA-ARS (United States)

A novel Surface Enhanced Raman Spectroscopy (SERS) method for fast and sensitive nondestructive detection was developed using silver colloid and a self-developed Raman system. Residual pesticides in fruits and vegetables have become one of the major food safety concerns around the world. At present, routine analytical methods used for the determination of pesticide residue on the surface of fruits and vegetables are destructive, complex, time-consuming, high cost and not environmentally friendly. SERS technology is a combination of Raman spectroscopy and nanotechnology. SERS can greatly enhance the Raman signal intensity, achieve single-molecule detection, and has a simple sample pre-treatment characteristic of high sensitivity and no damage; in recent years it has begun to be used in food safety testing research. In this study a rapid and sensitive method was developed to identify and analyze mixed pesticides of chlorpyrifos, deltamethrin and acetamiprid in apple samples by SERS. Silver colloid was used for SERS measurement by hydroxylamine hydrochloride reduced. The advantages of this method are seen in its fast preparation at room temperature, good reproducibility and immediate applicability. Raman spectrum is highly interfered by noise signals and fluorescence background, which make it too complex to get good result. In this study the noise signals and fluorescence background were removed by Savitzky-Golay filter and min-max signal adaptive zooming method. Under optimal conditions, pesticide residues in apple samples can be detected by SERS at the level of parts per million for individual chlorpyrifos, deltamethrin and acetamiprid, respectively. Most of these detection limits meet the maximum residue limits established by Chinese Standard. When mixing the three pesticides at low concentrations, their characteristic peaks can still be identified from the SERS spectrum of the mixture. Based on the synthesized material and its application in SERS operation, the method represents an ultrasensitive SERS performance in apple samples detection without sample pre-treatment, which indicates that it could be served as a useful means in monitoring pesticide residues.

9488-28, Session PTue

Rapid detection of benzoyl peroxide in wheat flour by using Raman scattering spectroscopy

Juan Zhao, Yankun Peng, China Agricultural Univ. (China); Kuanglin Chao, Jianwei Qin, Agricultural Research Service (United States); Sagar Dhakal, China Agricultural Univ. (China); Tianfeng Xu, CAU (China)

Benzoyl peroxide is a common flour that improves the whiteness of flour and the storage properties of flour products. However, benzoyl peroxide adversely affects the nutritional content of flour, and excess consumption causes nausea, dizziness, other poisoning, and serious liver damage. This study was focus on detection of the benzoyl peroxide added in wheat flour. Raman scattering spectroscopy system was used to acquire spectral signal from sample data and identify benzoyl peroxide based on Raman specral peak position. The optical devices consisted of Raman spectrometer and CCD camera, 785 nm laser, optical fiber, prober, and a translation stage to develop a real-time, non-destructive detection system. Pure flour, pure benzoyl peroxide and different concentrations of benzoyl peroxide mixed with flour were prepared as three sets samples to measure the Raman spectrum. These samples were placed in the same type of petri dish to maintian a fixed distance between the Raman CCD and petri dish during spectral collection. The mixed samples were worked by pretreatment of homogenization and collected multiple sets of data of each mixture. The exposure time of this experiment was set at 0.5s. The Savitzky Golay (SG) algorithm and polynomial curve-fitting method was applied to remove the fluorescence background from the Raman spectrum. The Raman spectral peaks at 890 cm-1, 1001 cm-1, 1234 cm-1, 1603cm-1, 1777cm-1 were identified as the Raman fignerprint of benzoyl peroxide. Based on the relationship between the Raman intensity of the most prominent peak at around 1001 cm-1 and log values of benzoyl peroxide concentrations, the chemical concentration prediciton model was developed. This research demonstrated that Raman detection system could effectively and rapidly identify benzoyl peroxide adulteration in wheat flour. The experimental result is promising and the system with further modification can be applicable for more products in near future.

9488-29, Session PTue

Nondestructive detection of pork quality based on dual-band VIS/NIR spectroscopy

Wenxiu Wang, Yankun Peng, China Agricultural Univ. (China); Yongyu Li, Xiuying Tang, CAU (China); Yuanyuan Liu, China Agricultural Univ. (China)

With the continuous development of living standards and the relative change of dietary structure, consumers' rising and persistent demand for better quality of meat is emphasized. Colour, pH value, tenderness, water-holding capacity (WHC) and water content are important quality attributes when evaluating meat. To realize nondestructive detection of multi-parameter of meat quality simultaneously is popular in production and processing of meat and meat products. The objectives of this research were to extract effective spectral information from two-band spectrum for rapid nondestructive and simultaneous detection of pork quality attributes. Reflectance spectra of 60 chilled pork samples were collected from a dual-band visible/near-infrared spectroscopy system which covered 400-1100 nm and 1000-2500 nm. Then colour, pH value, tenderness, WHC and water content were determined by standard method as reference value. Fourier filtering and standard normal variables transform (SNVT) were employed to eliminate the spectral noise. A spectrum connection method was put forward for effective integration of the dual-band spectrum to make full use of the whole efficient information. Partial least squares regression (PLSR) was applied to establish prediction models using full spectral information and extracted efficient variables based on single-band spectrum and dual-band spectrum, respectively. The experimental results showed that the model based on dual-band spectral information was superior to the models based on single band spectral information with lower root mean square error (RMSE) and higher accuracy. This mainly because dual-band spectrum can provide sufficient and comprehensive information which reflected the quality attributes. Data fusion from dual-band spectrum could significantly improve pork quality parameters prediction performance. The research also indicated that multi-band spectral information fusion had potential to comprehensively evaluate other quality and safety attributes of pork.

9488-30, Session PTue

Depth of penetration of a 785-nm wavelength laser in milk powder

Kuanglin Chao, Sagar Dhakal, Jianwei Qin, Moon S. Kim, Agricultural Research Service (United States); Yankun Peng, China Agricultural Univ. (China); Walter F. Schmidt, Agricultural Research Service (United States)

Raman spectroscopy is a useful, rapid, and non-destructive method for both qualitative and quantitative evaluation of chemical composition. Raman-based detection of contaminants in dry powder samples such as milk powder can be performed, but the penetration depth of the laser into the sample material is an important factor to ensure effective contaminant detection. The aim of this study was to investigate the penetration depth of a 785-nm laser (585-mw) into a sample of dry milk powder. Milk powder samples were prepared on a teflon slab with sample depths ranging from 1 mm to 10 mm, in increments of 1 mm. Known to exhibit identifiable Raman peaks, the teflon was used as a subsurface reference material. Analysis of the sample spectra for characteristics of teflon and characteristics of milk allowed for determination of the effective penetration depth of the laser light in the samples.

9488-31, Session PTue

Rapid detection of salmonella typhimurium through improvements to magnetoelastic biosensors

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A standard label-free biosensor is composed of molecular recognition probes immobilized on a sensor platform. While the sensitivity and ease of measurement are characteristics of the sensor platform, selectivity and avidity are properties of the molecular probe. Magnetoelastic (ME) biosensors composed of phage-displayed peptide probes and ME particles have shown significant promise for their sensitivity, cost effectiveness, and user-friendliness. We previously developed methods for enhanced isolation of highly selective phage-displayed oligopeptide probes and stable affinity-immobilization of the probes on ME platforms. Using these methods, we isolated highly selective Salmonella enterica serovar Typhimurium probes that do not bind to other serovars of pathogenic Salmonella, tagged them with Strep II tag for affinity immobilization, and immobilized them on a streptavidin coated 0.03 mm x 0.4 mm x 2 mm ME platform. We determined that the linear limits of detection for our biosensor were from 102 to 106 cells. Our biosensor was highly selective for detection of S. Typhimurium and did not react with E. coli O157:H7, S. Enteritidis, or S. Newport. When compared to the biosensor coated with the E2 landscape phage probe that had been previously utilized for detection of S. Typhimurium, our biosensor demonstrated higher sensitivity at bacteria concentrations up to 106 cells. Our results validated our previous approaches to improve the probe aspect of the ME biosensors. Although we demonstrated the efficacy of our approach for rapid detection of S. Typhimurium, our techniques can be easily adapted for detection of any organism including foodborne and agriculturally important bacterial pathogens.

9488-32, Session PTue

The blocking reagent optimization for the magnetoelastic biosensor

Jiajia Hu, Changzhou Univ. (China) and Auburn Univ. (United States); Yating Chai, Shin Horikawa, Auburn Univ. (United States); Howard C. Wikle, Auburn University (United States); Feng'en Wang, Institute of Quality Standard & Testing Technology for Agro-products (China); Songtao Du, Auburn University (United States); Bryan A. Chin, Auburn Univ. (United States); Jing Hu, Changzhou Univ. (China)

A biosensor essentially consists of two main components viz., a physical transducer and a biorecognition element. A magnetostrictive platform can serve as the transducer, since it offers wireless or remote detection, a unique advantage over conventional sensor platforms. Filamentous phage can be used as the biorecognition element due to its ability to bind bacteria with high specificity and selectivity. For all practical applications, it is very essential for both major components to be robust enough to withstand the rigors of conditions encountered in the field. Unfortunately, it has been found that corrosion of the surface of the magnetostrictive material can occur. In this study, fundamental research was conducted to identify possible factors leading to the corrosion of magnetostrictive biosensors. The effect of different buffer solutions (Distilled water, TBS and PBS), exposure time, BSA blocking agent, dissolved oxygen content and pH on the corrosion behavior of magnetostrictive biosensors are presented and discussed in this paper.

9488-33, Session PTue

Determination of the optimal analytical conditions for quickly detecting feces to cause contamination of potential pathogens in the field of agriculture using hyperspectral imaging

Hyunjeong Cho, Sungyoun Kim, Dongho Kim, Byuncheon Kim, Byunglim Cho, NAQS (Korea, Republic of)

As the interest of the consumers about the food quality and safety is growing and the outbreak caused by pathogenic microorganism has been emerged as an international trade issue, to ensure food safety for potential pathogens has been expanding in importance. Contamination by pathogenic microorganism is different from agricultural chemicals artificially imposed such as pesticides and contaminated through potential various paths, and may lead to serious outbreak when contaminated agricultural produce are placed at inappropriate temperature and potential pathogens are growing. Pathogenic microbial contamination of agricultural products are known to be introduced through the various paths. It has been considered of introduced pathway that Contaminated irrigation water, the use of manure amended with pathogenic microorganisms, or unhygienic administration in harvest.

In this study, using a hyperspectral imaging system that are being developed to ensure food quality and safety and available to discriminate the desired products from other unwanted materials, the optimal analytical conditions for quickly detecting feces to cause contamination of potential pathogens was established in the field of agriculture and harvest. Also they was introduced to potable hand -held equipment. In the future, this equipment is expected to evaluate through application studies in agricultural field.

9488-34, Session PTue

Development of a quality monitoring method for Korean traditional rice wine ‘makgeolli’ using near-infrared spectroscopy

Dae Yong Kim, Kyungdo Kwon, Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of)

A rapid nondestructive measurement method was developed to evaluate the quality of Korean traditional rice wine, Makgeolli using Fourier transform Near-infrared (FT-NIR) spectroscopy. The best PLSR model was developed for monitoring the quality of Makgeolli such as ethanol, reducing sugar and total acidity, respectively. The best calibration model for ethanol amount was achieved with the maximum of normalization. The coefficient of determination of prediction (R2) and standard error of prediction (SEP) of ethanol amount were 0.973 and 0.760%. In the reducing sugar amount, the best calibration model was achieved with raw data. The coefficient of determination of prediction and SEP were 0.962 and 0.729%. The best calibration model for total acidity was indicated by mean of normalization. The coefficient of determination of prediction and SEP of total acidity were 0.939 and 0.037%. The feasibility of the system and developed PLSR models might be able to replace the conventional quality monitoring methods of Makgeolli, which have been dependent on the experience of the field experts and expensive and time-consuming laboratory equipment.

9488-35, Session PTue

Hyperspectral fluorescence imaging with violet LED excitation for monitoring drought stress effect on soybean plants

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Soybean growth is affected by unfavorable environmental factors such as drought, extreme temperatures, and nutrient deficiency. This study investigated a nondestructive method for monitoring drought stress effect of soybean plants seeds based on hyperspectral fluorescence imaging. Drought stress was imposed on soybean plants during 15 days. The fluorescence spectra of soybean leaves in the range from 464 to 800 nm were extracted from hyperspectral fluorescence images obtained using violet LED excitation of 405 nm. Optimal combination of multispectral images for the measurement of drought stress of soybean plants was examined. Soybean plants with drought stress over six days and with non-drought stress were classified. The results demonstrate fluorescence imaging technology based on violet LED has the potential to monitor the water deficient conditions of soybean plants.

9488-36, Session PTue

Multispectral imaging for browning detection of fresh-cut lettuce

Changyeun Mo, Giyoung Kim, Jongguk Lim, National Academy of Agricultural Science (Korea, Republic of); Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of); Moon S. Kim, Agricultural Research Service (United States)

Lettuce accounts for the largest portion of fresh-cut agricultural products in South Korea. The complete removal of browning on lettuce during the cleaning process is difficult. Defects on lettuce such as browning are required to be screened before the cleaning process. In this study, a rapid detection method of browning on lettuce was developed using multispectral imaging technique. Reflectance spectra of lettuce in the range from 400 to 1000 nm range were collected from hyperspectral reflectance images obtained using blue, green, and red LED illumination. Multispectral imaging algorithms were developed to discriminate sound and browning portion on lettuces. Multispectral algorithm can potentially be useful for the defect detection of fresh-cut lettuce.

9488-37, Session PTue

Hyperspectral imaging for contaminant detection in starch

Min Huang, Jiangnan Univ. (China) and Agricultural Research Service (United States); Moon S. Kim, Kuanglin Chao, Jianwei Qin, Agricultural Research Service (United States); Qibing Zhu, Jiangnan Univ. (China)

As an industrial adhesive, maleic anhydride was not approved for use in food, but food starch in night markets sold from a supplier in Tainan city, Taiwan, were found to contain maleic anhydride in December, 2013. This study was aimed at exploring the feasibility of maleic anhydride detection using NIR hyperspectral imaging for food starch. Hyperspectral reflectance images from 937.5 nm -1653.7 nm were captured. Following image preprocessing (normalization and background removal), the spectrum of each pixel in the sample images was classified by band ratio method. Chemical images were created for the distribution of maleic anhydride particles within images of starch mixture samples that were prepared with different concentrations (5%, 1%, 0.5%). The study demonstrated that hyperspectral imaging technique was an effective method for maleic anhydride adulteration detection in food starch.

9488-38, Session PTue

Production of an innovative fertilizer from organic waste: process monitoring by hyperspectral imaging

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The European directive 2008/98/CE establishes a legal framework for the treatment of waste within the Community. It aims at protecting the environment and human health through the prevention of the harmful effects of waste generation and waste management. In order to better protect the environment, the Member States should adopt measures for the treatment of their waste according to a hierarchy as outlined: prevention, preparing for reuse, recycling, energy recovery, disposal.

In this context, the European project LIFE12 ENV/IT/000356 "RESAFE" is addressed to produce and utilize a new class of fertilizers characterized by reduced salinity in order to substitute chemical and mineral fertilizers through a technological route based on Urban Organic Waste (UOW), Farm Organic Residues (FOR), Bio-Chars (BC) and Vegetable Active Principles (VAP) processing. Following this approach, it will be possible for farmers and urban waste managers to reduce costs and to obtain environmental and economic incomes. Furthermore, environmental impacts will be also reduced contributing to decrease the greenhouse emissions from landfills and from the production of mineral fertilizers.

In this paper, specific innovative sensing architectures, based on HyperSpectral Imaging (HSI) devices working in the near infrared (NIR) range, and related detection architectures, is presented and discussed in order to define and apply smart detection engines to follow the transformations of the complex material, resulting from UOW, FOR, BC and VAP based recipes during the different stages of the fertilizer production process. Results show as the fertilizer production process can be monitored adopting the NIR-HSI approach.

9488-47, Session PTue

Prediction of soluble solids content spatial distribution in apple using hyperspectral imaging and variable selection algorithms

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Today, determination of soluble solids content in apple based on hyperspectral imaging is slow for the long acquisition time of hyperspectral images. Therefore it is important to select effective wavelengths from the hyperspectral images to decrease the acquisition time. In this study, ant colony optimization (ACO) and successive projections algorithm (SPA) were used for extracting effective wavelengths from 769 wavelengths of 400~1 000 nm hyperspectral images of 'Fuji' apples. A total of 160 samples were prepared for the calibration (n=120) and prediction (n=40) sets. Based on the 46 and 40 effective wavelengths selected by ACO and SPA respectively, different models were built and compared for predicting soluble solids content (SSC) in apple using partial least squares (PLS) and multiple linear regression (MLR). Within all the models, the SPA-MLR achieved the best results, where , RMSEP and RPD were 0.9434, 0.3322 and 4.2033 respectively. However, , and of the ACO-MLR model were 0.8046, 0.6921 and 2.2622 respectively, which was not a good results compared with these of the PLS model based on 769 wavelengths. Results showed that ACO and SPA can be used for selecting the effective wavelengths from hyperspectral images. SPA-MLR is an optimal modeling method for prediction of SSC in apple and has a great potential for on-line detection of SSC in apple. The soluble solids content spatial distribution on apples was determined at the same time.

9488-13, Session 3

Second derivative analyses of temperature dependent Raman spectroscopy

Walter F. Schmidt, Leigh Broadhurst, Jianwei Qin, Kuanglin Chao, Daniel Shelton, Moon S. Kim, Agricultural Research Service (United States)

No Abstract Available

9488-14, Session 3

Dry mixture preparation by resonant acoustic mixing for Raman-spectroscopy-based contaminant detection

Sagar Dhakal, Kuanglin Chao, Jianwei Qin, Moon S. Kim, Agricultural Research Service (United States)

Developing non-destructive ingredient authentication and screening methods using Raman spectroscopy for food safety inspection requires the preparation of sample mixtures of food materials that contain contaminants at low concentrations. The experiments require the sample mixtures to have extremely high degrees of uniformity in order to effectively develop methods for the contaminant detection levels targeted. In this study, dicyandiamide was mixed into dry milk powder at concentrations (w/w) between 0.05% and 1.0%. Resonant acoustic mixing technology was used to produce samples of extremely high uniformity in mixture composition. Analysis of the Raman spectra from the sample mixtures showed linear relationships between the Raman intensities and the chemical concentrations. The method and procedures of this study form a basis for the future development of Raman spectroscopy-based quantitative evaluation protocols for detection of contaminants in food ingredients.

9488-15, Session 3

Screening of adulterants in powdered foods and ingredients using line-scan Raman chemical imaging

Jianwei Qin, Kuanglin Chao, Moon S. Kim, Agricultural Research Service (United States)

Powdered foods and ingredients are widely consumed by final consumers and extensively used as basic materials for food productions in various food industries. Economically motivated adulteration and fraud are emerging food safety risks that threaten the health of the general public. The capacity for rapid and accurate authentication of the powdered foods and ingredients is an important part of food safety programs. In this study, a newly developed line-scan macro-scale Raman chemical imaging system was used to realize high-throughput screening of adulterants and illegal additives mixed in the powdered foods and ingredients. The system utilizes a 785 nm line laser to project a 24 cm long excitation line on the sample surface. A detection module consisting of a dispersive imaging spectrograph and a CCD camera is used to acquire Raman scattering signals along the laser line. Hyperspectral Raman image data is accumulated line by line as a motorized table moves the samples transversely through the laser line. The system was used to collect Raman images from representative powdered foods and ingredients (e.g., dry milk, flour, and starch) mixed with selected adulterants and illegal additives (e.g., melamine, azodicarbonamide, and maleic anhydride) at different concentration levels. Raman spectral and image processing algorithms were developed to visualize the adulterant and additive particles in the food powders.

9488-16, Session 3

Shifted excitation Raman difference spectroscopy: a potential tool for outdoor measurements in precision agriculture

Martin Maiwald, André Müller, Ferdinand-Braun-Institut (Germany); Jörn Selbeck, Jana Käthner, Manuela Zude, Leibniz-Institut für Agrartechnik Potsdam-Bornim e.V. (Germany); Dominique Fleury, Univ. of Applied Sciences at Changins (Switzerland); Bernd Sumpf, Götz Erbert, Günther Tränkle, Ferdinand-Braun-Institut (Germany)

The development of compact excitation light sources such as diode lasers and miniaturized spectrometers brought Raman spectroscopy out of the lab and enables application fields such as the in situ detection of explosives, point-of-care diagnostics, and food analysis. The latter becomes more and more important in precision agriculture. Here, the monitoring of fruit quality, moisture needs, and plant health are only a few aspects. However, outdoor measurements in the field have additional challenges. Autofluorescence of biological samples and impurities on peel surfaces can mask the Raman signals. Moreover, daylight with its broad background signal and additional narrow lines can significantly complicate the detection and the analysis of weak Raman signals. Shifted Excitation Raman Difference Spectroscopy (SERDS) is a powerful spectroscopic tool for efficient separation of Raman signals from background interference.

In this work SERDS using a dual-wavelength diode laser at 785 nm will be presented as a potential tool for outdoor measurements in precision agriculture.

The diode laser generates two excitation lines with an optical power up to 100 mW and a spectral spacing of about 10 cm-1. Here, the device has a power consumption of 0.7 W. Together with a footprint of 0.5 x 3 mm2 it enables the integration into portable sensor systems. An electro-optical and spectral characterization of this light source will be given. Raman experiments under daylight conditions are carried and demonstrate the suitability of SERDS for outdoor measurements. Pilot investigations on apples show the potential of this setup for in situ measurements in precision agriculture.

9488-17, Session 4

Color-based hyperspectral imaging for safety inspection of poultry carcasses

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Researchers at the USDA-ARS have developed hyperspectral imaging system and technology for real-time online safety inspection of poultry carcasses, including systemic disease and fecal material detection. This paper extends the previous work by identifying color machine vision technology that can use the hyperspectral image classification models for the food safety inspection of poultry carcasses. So far, the use of hyperspectral image processing algorithms for food safety and quality inspection applications has been largely limited to hyperspectral imaging system. The ultimate goal of a study with color machine vision for hyperspectral imaging is to develop a cost-effective imaging solution using a traditional digital color camera and the state-of-the-art hyperspectral image processing algorithms for food inspection applications. The specific objectives of this study are 1) to develop a hyperspectral reflectance reconstruction technique using color images, 2) to evaluate the performance of the spectral image reconstruction models in terms of spectral recovery accuracy, and 3) to evaluate the performance of the hyperspectral image processing algorithms with reconstructed hyperspectral images in terms of disease and fecal detection. A proof-of-concept study will be performed to develop prediction models to recover hyperspectral images with RGB color images simulated from hyperspectral images. The accuracy of the reconstructed hyperspectral curves will be evaluated over the wavelength range from 400 to 700 nm and the five individual wavelengths (517, 565, 580, 600 and 620 nm), identified for the systemic disease and fecal material detection applications. The performance of detection with reconstructed hyperspectral images will be also evaluated.

9488-18, Session 4

Chemometric analysis for near-infrared spectral detection of beef in fish meal

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This paper reports the chemometric analysis of near-infrared spectra drawn from hyperspectral images to develop, evaluate, and compare statistical models for the detection of beef in fish meal. There were five pure-fish samples, five pure-beef samples, and sixty-four fish/beef mixture samples prepared for hyperspectral line-scan imaging by a machine vision system. Spectral data for four hundred pixels (400 individual spectra) were retrieved from every sample image. The spectral data spanning 969 nm to 1631 nm (across 200 spectral bands) were analyzed. Statistical models were built using the partial least squares regression (PLSR) and the principal component analysis (PCA) methods. The models were created and developed using the spectral data from the pure-fish and pure-beef samples, and were tested and evaluated using the data from the mixture samples. The objective of this study was to detect any beef present in fish meal samples, and to estimate the percentage of beef present in fish-beef mixtures.

9488-19, Session 4

Application of hyperspectral imaging and spectral similarity analysis for intramuscular fat quantification in beef

Santosh Lohumi, Sangdae Lee, Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of)

Intramuscular fat content of beef is an important meat trait because it is related to human nutrition and health and sensory meat properties. Existing chemical procedures are very exhaustive and do not fulfill the conditions for routine analysis in the industry. Thus, the meat industry is still in need of fast and reliable methods with the potential of industrial use. In recent years, hyperspectral imaging has gained a wide recognition as a non-invasive and rapid quality and safety evaluation method for a wide range of food products including meat. In this paper, the potential use of hyperspectral imaging (HSI) in combination with spectral similarity analysis for the determination of intramuscular fat content in beef was evaluated. Hyperspectral image of beef samples with different intramuscular fat concentration were acquired. Intramuscular fat content was chemically extracted and quantified for the same samples. Following imaging processing, spectral similarity measure including, spectral information divergence (SID), spectral angle measure (SAM), and Euclidian distance measure (EDM), which was based on quantifying the spectral similarities by using a predetermined fat reference spectrum, was performed on the hyperspectral image of the beef samples for visualization and determination of intramuscular fat. The three similarity analysis method showed a comparable result for intramuscular fat detection and imaging allowed visualization of distribution of intramuscular fat within the samples. Our results show that HSI technique and spectral similarity analysis is a promising non-invasive method to determine intramuscular fat content in beef and can also be applied to detection of different properties in different kind of meat samples.

9488-20, Session 4

The use of short wave infrared hyperspectral imaging for discrimination of watermelon seed infestation by acidovorax citrulli

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The bacterial fruit blotch of cucurbit plants caused by Acidovorax citrulli leads to a serious problem to growers and seed producers because it is difficult to prevent spreading through causal agent of seeds. Conventional detection methods for infected seed such as a biological, serological, and molecular measurement are not practicable to measure whole samples because these methods are time-consuming and require expensive equipments. Therefore, it is necessary to develop novel technique which is able to detect seeds infestation non-destructively and rapidly. The short-wave infrared (SWIR) hyperspectral imaging system is used to discriminate infected seeds from healthy seeds as a rapid, accurate, and nondestructive detection tool. Detection algorithms based on partial least square discriminant analysis (PLS-DA) and least square support vector machine (LS-SVM) were developed to discriminate between infected and healthy seeds. The SWIR hyperspectral imaging system could achieve high accuracy (95%) to discriminate infected seeds from healthy seeds. This study shows that SWIR hyperspectral imaging system has a good potential for detection of infected seeds from healthy seeds.

9488-21, Session 4

Spectroscopic techniques for examination of toxic metabolites in maize kernels

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The official method, HPLC to determine grain safety is expensive and time consuming, since spectroscopic techniques are emerging for detection of toxic metabolites in agricultural commodities. These methods are effortless and provide non-destructive measurements. Aflatoxins are the toxic metabolites produced by certain mold fungi, Aspergillus flavus and Aspergillus parasiticus. Aflatoxins are considered as highly carcinogenic (cancer causing) to animal and human. In this study, we purpose various spectroscopic techniques for the detection of aflatoxin B1 (AFB1) in maize kernels. Maize samples were artificially spiked with different AFB1 concentrations (derived from A. falvus) ranging from 10 μg/kg to 500 μg/kg, while pure samples were surface disinfected with PBS solution. Afterwards, both contaminated and pure samples spectra were collected through various spectroscopic modalities in particular hyperspectroscopy, fluorescence spectroscopy and FT-NIR spectroscopy. Partial least square discriminant analysis (PLS-DA) and support vector machine (SVM) models were developed to successfully differentiate pure samples from contaminated samples of different concentration. Results from both models indicated adequate classification accuracy between pure and contaminated groups, moreover we generated contamination map from PLS-DA model that provide the visual information about the AFB1 contamination region or pixel of the maze sample. Our results suggest that spectroscopic techniques are highly effective to detect contamination in agriculture products with non-destructive manner and could be an alternative tool to replace conventional methods.

9488-22, Session 5

Classification of corn kernels contaminated with aflatoxins using fluorescence and reflectance hyperspectral images analysis

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Aflatoxins are secondary metabolites produced by certain fungal species of the Aspergillus genus. Aflatoxin contamination remains a problem in various agricultural products due to its toxic and carcinogenic properties. Conventional chemical analytical methods for quantification of aflatoxins in grain samples are time-consuming, expensive and destructive. Due to its rapid and non-destructive methodology, hyperspectral imaging may provide an alternative approach for detecting aflatoxins. This study focused on employing fluorescence and reflectance visible near-infrared (VNIR) hyperspectral imaging systems to classify aflatoxin contaminated corn kernels. Corn ears were artificially inoculated in the field with toxigenic A. flavus spores at the early dough stage of kernel development. After harvest, a total of 300 kernels were collected from corn ears. These kernels were visually separated into three different groups: those that are fluorescent, adjacent to inoculation site, and not near the inoculation site as controls. Fluorescence hyperspectral imagery with ultraviolet excitation and reflectance VNIR hyperspectral imagery with halogen light, were acquired on both sides (germ and endosperm) of the kernels. All kernels were then subjected to chemical analysis individually to determine their aflatoxin contamination levels. Region of interest (ROI) was created for all kernels to extract averaged spectra for subsequent data analysis. The fluorescence and reflectance spectra were plotted for all three treatment groups and for both sides of the kernels, to examine the spectral differences between germ and endosperm sides, and among the three visually designated groups. All the kernels are pooled together and divided into "healthy" and "contaminated" groups based on a 20 ppb threshold. Results from linear discriminant analysis using fluorescence and reflectance data will be compared for germ and endosperm sides.

9488-23, Session 5

Discrimination of varieties of pear based on Vis/NIR spectroscopy and BP-ANN

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Three different varieties of pear were identified with visual/near infrared spectroscopy (NIRS) technology. The samples data were analyzed with the whole wave band and characteristic wave band (420~650nm, 825~1100nm and 1400-1550nm) models, respectively. The first three principal components (PC) were obtained by principal component analysis (PCA) and used as the input variables of back-propagation artificial neural network (BP-ANN) which included one hidden layer, while the values of pear varieties were used as the output variables of BP-ANN, and then the three layers BP-ANN discrimination model was built. In addition, three pre-processing methods including average smoothing, first and second derivatives were applied to improve the predictive ability of models. The identification results from 30 unknown samples showed that the discriminating rates were 100% in both models with average smoothing, and the accuracy of characteristic wave band is better than that of the whole wave band model. The results also indicated that it is feasible to discriminate the variety of pear by visible/near infrared reflectance spectra as a rapid and non-contact way, and selecting characteristic wave band is one of the validated methods to improve the precision of the discrimination model.

9488-24, Session 5

Using NOAA/AVHRR based remote sensing data and PCR method for estimation of Aus rice yield in Bangladesh

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Rice is a dominant food crop of Bangladesh accounting about 75 percent of agricultural land use for rice cultivation and currently Bangladesh is the world's fourth largest rice producing country. Rice provides about two-third of total calorie supply and about one-half of the agricultural GDP and one-sixth of the national income in Bangladesh. Aus is one of the main rice varieties in Bangladesh. Crop production, especially rice, the main food staple, is the most susceptible to climate change and variability. Any change in climate will, thus, increase uncertainty regarding rice production as climate is major cause year-to-year variability in rice productivity. This paper shows the application of remote sensing data for estimating Aus 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. The simulated result was compared with official agricultural statistics showing that the error of estimation of Aus rice yield was less than 10%. Remote sensing, therefore, is a valuable tool for estimating crop yields well in advance of harvest, and at a low cost.

9488-48, Session 5

Pest damage assessment in fruits and vegetables using thermal imaging

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In some fruits and vegetables, it is difficult to visually identify the ones which are pest infested. This particular aspect is important for quarantine and commercial operations. In this article, we propose to present the results of a novel technique using thermal imaging camera to detect the nature and extent of pest damage in fruits and vegetables, besides indicating the level of maturity and often the presence of the pest. Our key idea relies on the fact that there is a difference in the heat capacity of normal and damaged ones and also observed the change in surface temperature over time that is slower in damaged ones. This paper presents the concept of non-destructive evaluation using thermal imaging technique for identifying pest damage levels of fruits and vegetables based on investigations carried out on random samples collected from a local market.

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9489-1, Session 1

3D range data compression with a virtual fringe projection system *(Invited Paper)*

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Over the past decades, 3D range scanning techniques have advanced rapidly and showed the great potential to penetrate into our daily life. Yet, unlike their 2D counterparts, storing enormously large 3D raw data become an issue since 3D range data compression techniques have not been well established. 3D range data are predominantly stored as mesh formats (e.g., STL, OBJ, PLY). These formats are designed to be generic and effective such that they could be used to represent arbitrary topologies; and they usually store (x, y, z) coordinates for each vertex of a polygon, the connectivity between vertices, and often normal and (u, v) map. However, they require a large storage space. Virtually creating a 3D range scanner with advanced computer graphics tools can be used to convert 3D shapes to regular 2D images by virtually re-scanning the objects. This method achieved great compression ratios without substantially losing data quality. However, because one 8-bit channel spatially encodes fringe orders for temporal phase unwrapping, these techniques are limited to use a small finite number of fringe stripes, resulting in relatively low-resolution 2D images for representing 3D geometries. The key limitation of the previous methods is the use of discontinuous "stair" type of channel for phase unwrapping. This paper presents a method to overcome such a limitation by making the channel as smooth sine and cosine functions without any discontinuities. Comparing with previously methods, this proposed method has higher compression ratio and has less significant artifacts due to lossy compression algorithms.

9489-2, Session 1

Phase unwrapping of fringe images for dynamic 3D measurements without additional pattern projection

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Fringe projection is an established method to measure the 3D structure of macroscopic objects. Adversely, the coding of fringe projection with usually more than one stripe is ambiguous. To determine object points with absolute position in 3D space, the coding has to be unique. Thus, there is need of an additional coding pattern to eliminate these stripe ambiguities. Especially in dynamic measurement situations each extra pattern without 3D information is counterproductive. This trade-off leads to a new approach of phase unwrapping.

The approach is based on an image segmentation of each view in areas without height jumps larger than a fringe period. These areas can be unwrapped without errors, but absolute values are dependent on the zero point. Using a stereo camera setup, the alignment of the phase maps of both areas is now required. For this purpose an arbitrary pixel is selected that is ideally not in the vicinity of the segment edge. The associated phase value of this point is then searched along the related epipolar line on the wrapped phase map in the corresponding image segment. All similar phase values are candidates for a real point correspondence. So, phase unwrapping is done for each candidate as zero point. To check which candidate is right, 3D data estimation by triangulation between the unwrapped phase maps of both views is applied. By back projection of this 3D data into the second view, the amount of overlay between the back projection and the image segmentation determines the right candidate.

To verify the presented approach, both synthetic data and real images of two stereo camera systems have been analyzed. In general, the number of candidates of correspondence decreased with the additional consideration of phase distribution on the projector plane. Thus, the robustness und calculation speed of this approach are increased. Furthermore, positive effects of an asymmetric alignment of the projector with respect to the stereo cameras have been shown. Taken together, our method results in object coordinates with an absolute position in 3D space without using additional projection pattern.

9489-3, Session 1

Experimental Verification of Reconstruction of Two Interfering Wavefronts Using the Transport of Intensity Equation

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One of the most challenging problems in interferometry is how to reconstruct two unknown interfering wavefronts from their interference patterns or reveals the error of the reference wavefront. Authors recently have extended the application of the TIE formula to the amplitude and the phase of the interference filed of two waves in paraxial approximation and technique has been verified by simulation.

In this work we present the experimental verification of interferometric TIE method. A Fizeau interferometer is used to test a flat surface. A PZT is attached to the back of the test surface to generate the phase shift between waves. A CCD is moved along the common propagation direction of the waves by a linear stage to record at least three intensity distributions to reveal the intensity derivative along z direction but due to mechanical error the recorded intensities show some lateral displacements that are removed by software. The wavefront of the object wave is also reconstructed with traditional TIE and compared with one that reconstructed from interferometric TIE method. The consistency and errors of the reconstructed waves is discussed and possible potential error sources are investigated. The issues such as computation time and spatial resolution of the reconstructed waves are discussed and possible applications of interferometric TIE are presented.

9489-4, Session 1

Geometric and topological feature extraction of linear and circular segments from 2D cross-section data of 3D point clouds

Rajesh Ramamurthy, Yi Liao, Ratnadeep Paul, Kevin G. Harding, Tao Jia, Vincent Lucas, GE Global Research (United States); Xiaoming Du, GE Global Research (China)

Optical measurement techniques are often employed to digitally capture three dimensional shapes of components. The digital data density output from these probes range from a few discrete points to exceeding millions of points in the point cloud. The point cloud taken as a whole represents

a discretized measurement of the actual 3D shape of the surface of the component inspected to the measurement resolution of the sensor. Embedded within the measurement are the various features of the part that make up its overall shape. Part designers are often interested in the feature information since those relate directly to part function and to the analytical models used to develop the part design. Furthermore, tolerances are added to these dimensional features, making their extraction a requirement for the manufacturing quality plan of the product. The task of "extracting" these design features from the point cloud is a post processing task. Due to measurement repeatability and cycle time requirements often automated feature extraction from measurement data is required. The presence of non-ideal features such as high frequency optical noise and surface roughness can significantly complicate this feature extraction process. This research describes a robust process for extracting linear and arc segments from general 2D point clouds, to a prescribed tolerance. The feature extraction process generates the topology, specifically the number of linear and arc segments, and the geometry equations of the linear and arc segments automatically from the input 2D point clouds. This general feature extraction methodology has been employed as an integral part of the automated post processing algorithms of 3D data of fine features.

9489-5, Session 2

Inner profile measurement probe: from a pipe to an underground cavity *(Invited Paper)*

Toru Yoshizawa, NPO 3D Associates (Japan); Toshitaka Wakayama, Saitama Medical Univ. (Japan)

We have been involved in developing probes for inner profile measurement of pipes, tubes and holes that may be large or small. Request for inner profile or diameter measurement of pipes and holes are becoming more and more important, and especially necessity for measuring smaller inner diameter is strong, that is, probes with a smaller size are required to meet requirement from various fields such as mechanical engineering, automobile and aircraft industry and civil engineering. Because a smaller size probe are applicable to a larger hole. 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 this ring beam device gives an inner cross-section of the objective. However, recent request for measuring smaller and smaller inner diameter is very large, and a conventional probe consisting of a glass or plastic tube with such devices as a CCD camera, a cone mirror and a LD built-in proved too large to check such smaller holes and as with a diameter smaller than 5mm. Hence we tried to utilize optical fibers. Up to now, a probe with the size of 5mm in diameter is under trial. As far as we checked the inner surfaces of smaller holes under 5mm in diameter, endoscopes and/or borescopes have been mainly used. However these are available only for observing the inside and not useful 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 addition, we are aiming to realize such a small size probe as 3mm in diameter. At the same time we are trying to develop a probe that is available for checking the size and volumes of an underground cavity with a cross sectional diameter of 10m or more.

9489-6, Session 2

Development of feature extraction analysis for a multi-functional optical profiling device applied to field engineering applications

Kevin G. Harding, GE Global Research (United States); Xu Han, Guangping Xie, GE Global Research (China); Brandon Laflen, GE Global Research (United States); Ming Jia, GE Global Research (China); Guiju Song, GE Global Research (United States)

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 describe a method based on 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 gaps, 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, a new dual ring design and future work will be discussed at the end of this paper.

9489-7, Session 2

Composite layup monitoring using structured light

Robert W. Tait, Kevin G. Harding, Christopher Nafis, GE Global Research (United States)

The making of composite parts involves laying down multiple layers of tape in an organized manner. Misplaced ends, wrinkles or other factors can cause the part being built to have weaknesses or other imperfections. However, the actual edges of the tape do not stand out well with each layer reacting differently to lighting. The fiber nature of the tape will make the surface appear bright in some orientations and very dark in other. To complicate the problem, each layer of tape needs to be laid down at different angles, so can be dark, light or in-between, and at positions to fairly tight tolerances. This paper presents a study of several methods for determining the tape position and flaws, and detail a structured light method for determining the tape position. Considerations of tolerances, experimental results and how such a system might be implimented will be presented.

9489-12, Session 2

Method for controlling a laser additive process using intrinsic illumination

Guoshuang Cai, Robert W. Tait, Sudhir Tewari, Magdi N. Azer, Xiaobin Chen, David Abbot, Yong Liu, Kevin G. Harding, GE Global Research (United States)

One form of additive manufacturing is to use a laser to generate a melt pool from powdered metal that is sprayed from a nozzle. The laser net-shape machining system builds the part a layer at a time by following a predetermined path. However, because the path may need to take many turns, maintaining a constant melt pool may not be easy. A straight section may require one speed and power while a sharp bend would over melt the metal as the same settings. This paper describes a process monitoring method that uses the intrinsic IR radiation from the melt pool along with a process model configured to establish target values for the parameters associated with the manufacture or repair. This model is based upon

known properties of the metal being used as well as the properties of the laser beam. An adaptive control technique is then employed to control process parameters of the machining system based upon the real-time measurement. Since the system uses the heat radiant from the melt pool, other previously laid metal does not confuse the system as only the melted material is seen by the camera.

9489-9, Session 3

Sensors for modern manufacturing: certify as you build *(Invited Paper)*

Jyoti Mazumder, Lijun Song, Univ. of Michigan (United States)

Modern manufacturing is increasingly becoming Digital manufacturing. Recently Additive Manufacturing (AM) has been hailed as the "third industrial revolution" by Economist magazine [April-2012]. Flexibility and capability of producing near net shape critical components directly from Computer Aided Design (CAD) is partly responsible for its attraction. Often it is used for low volume manufacturing which may benefit from in situ diagnostics and quality inspection. Sophisticated science based in-Situ diagnostic techniques are needed to produce defect free parts with acceptable properties. Post mortem measurement of part dimension with conventional metrology is not adequate. With the in-situ determination of defects, microstructure and composition it will have the potential to revolutionize the manufacturing practice by offering a new route to engineer structures and properties as desired. New optical Sensors being developed to control geometry using imaging, cooling rate by monitoring temperature, microstructure, temperature and composition using optical spectra. Ultimately these sensors will enable one to "Certify as you Build".

9489-10, Session 3

A brief survey of sensing for additive manufacturing *(Invited Paper)*

Edward W. Reutzel, Abdalla R. Nassar, Applied Research Lab. (United States)

Additive manufacturing of metal parts is a complex process, fraught with many potential opportunities for failure. Parts may require thousands of individual laser or electron-beam deposits, and conditions may fluctuate during processing, e.g. material feed rate or packing density, beam power or spatial energy distribution, environment gas composition, local and global temperature, and build geometry. Such process variations affect final part geometry, microstructure, properties, and final part quality. To provide practitioners confidence that each part is produced consistently without defects, researchers have developed a variety of sensing methodologies for quality control, including thermal imaging of melt pool, monitoring of temperature or layer build-height, laser beam power, and others. This brief survey addresses sensor investigations that are being undertaken to support this important technology.

9489-8, Session 4

Characterization of 3D printing output using an optical sensing system

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

This paper presents the experimental design and initial testing of a system to characterize the progress and performance of a 3D printer. Currently, 3D printing – particularly in the consumer realm – operates blindly. If there is a problem, such as the filament running out or an object detaching from the plate, the printer has no way of knowing this and continues printing (generally making a mess). By identifying problems during printing, it may be possible to correct them (if, for example, an issue with a layer is detected before the printer starts on the next layer) or to abort the print job (saving material, electricity and clean up time).

A similar need exists for assessing objects produced through 3D printing: items need to be assessed before being used for applications where a defect could injure a person or cause other problems. This inspection can be performed manually; however, this is time consuming and expensive. Traditional assessment techniques, which are based on comparison to a perfect or near-perfect specimen are problematic when assessing the type of bespoke items typically produced by 3D printers.

The system presented seeks to characterize printing progress and quality through comparison to a model. It is based on five Raspberry Pi single-board computers. It collects images of the 3D printed object, which are compared to an ideal model. The system, while suitable for printers of all sizes, can potentially be produced at a sufficiently low cost to allow its incorporation into consumer-grade printers. The efficacy and accuracy of this system is presented and discussed. The paper concludes with a discussion of the benefits of being able to characterize 3D printer performance and a discussion of future work.

9489-11, Session 4

Thickness and air gap measurement of assembled IR objectives

Bernd Lueerss, Patrik Langehanenberg, TRIOPTICS GmbH (Germany)

A growing number of applications like surveillance, thermography, or automotive demand for infrared imaging systems. Their imaging performance is significantly influenced by the alignment of the individual lens elements. Besides the lateral orientation of lenses, the air spacing between the lenses is a crucial parameter. Because of restricted mechanical accessibility within an assembled objective, a non-contact technique is required for the testing of these parameters. So far commercial measurement systems were not available for testing of IR objectives since many materials used for infrared imaging are non-transparent at wavelengths below 2 μm. We herewith present a time-domain low coherent interferometer capable of measuring any kind of infrared material (e.g., Ge, Si, etc.) as well as VIS materials. In a fiber-optic Michelson-Interferometer the light from a broadband superluminescent diode is split into a reference arm with a variable optical delay and a measurement arm where the sample is placed. On a photo detector, the reflected signals from both arms are superimposed and recorded as a function of the variable optical path. Whenever the group delay difference is zero, a coherence peak occurs and the relative lens' surface distances are derived from the optical delay. In order to penetrate IR materials, the instrument operates at 2.2 μm.

The set-up allows the contactless determination of thicknesses and air gaps inside of assembled infrared and VIS objective lenses with accuracy in the micron range. It therefore is a tool for the precise manufacturing or quality control.

9489-13, Session 4

The impact of oceanic gravity waves on laser propagation

Serdar Kizilkaya, Cumhuriyet Mah. (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.

9489-14, Session 5

Measuring accuracy of in-plane and out-of-plane deformations simultaneous measurement of speckle interferometry using multi-recording method *(Invited Paper)*

Yasuhiko Arai, Kansai Univ. (Japan)

A novel in-plane and out-of-plane deformation simultaneous measurement method using only two speckle patterns grabbed before and after deformation of an object with rough surfaces has been proposed. The optical system is set up by improving ordinary two-beam speckle interferometer. In the new optical system, because a phenomenon of in-plane and out-of-plane deformation can be simultaneously recorded by only one camera by using the multi-recording method of speckle patterns, the system does not require any confused setting up the optical system. For example, alignment of the axes of plural numbers of cameras, setting of multiplication factor of plural cameras, adjustment of timing of sampling of plural cameras in dynamic events, and so on are not required. Therefore, the optical system based on the new method can be readily applied to three-dimensional deformation measurement. At the same time, the high resolution measurement of deformation is also realized. However, it is thought that there are some problems concerning measuring accuracy, because plural dimensional data has to be grabbed by single camera. In this paper, some error sources of in-plane and out-of-plane deformations simultaneous measurement of speckle interferometry using multi-recording method are discussed. The influence of factor of each error source to measuring accuracy of the method is investigated by using experimental results. Possibility of high resolution three-dimensional measurement by using proposed optical system is also discussed.

9489-15, Session 5

Long wave infrared 3D scanner

Ernst Wiedenmann, Robert Schott, Jan Tusch, Andreas Wolf, Mohsen Afrough, Sven Albert, Aimess Services GmbH (Germany)

In industrial metrology, the system of fringe projection for the rapid determination 3D surface data is established. The combination of areal and structured projection with two-dimensional optical sensors and triangulation measurement principle allows dense point clouds with sufficient accuracy. State of the art systems have great difficulty with very dark surfaces. Transparent materials cannot be measured using the visible spectrum of light without surface preparation. We have therefore developed a new structured light projection system that solves these problems. For the first time in the geometric measurement technology, the physical principle of energy conversion is utilized.

Existing structured light projection systems are based on the reflection of electromagnetic radiation. Instead of reflection, our system relies on the absorption of the object. This enables the measurement of previously inaccessible surfaces, but calls for the transition to other radiation sources. We choose the infrared wavelength range, since most materials, which are transparent for visible light, show a strong absorption in this area. The absorbed energy is converted to heat, which can be detected by an infrared detector. The emitted radiation has two major advantages. On the one hand heat radiation is an ideal Lambertian radiator. This means that the radiation density is constant in all directions in space, and thus the detection is independent of direction. On the other hand, both absorption and emission are usually confined to the surface.

For the calculation of 3D-Points and for calibration of the infrared system, there have been developed new algorithms based on state of technology. We use phase shifting technique for reconstruction of single measurement points. Therefore, we get for each camera pixel one 3D Point, which is essential in the infrared regime due to sensors with little number of pixels. Unique reconstruction of the 3D scene is done by a multi-period method.

Our development shows that this new technology offers a significant potential for industrial metrology. Using a projector model and calibration method developed by the Fraunhofer IFF in Magdeburg, we show 3D data on glass, PMMA, carbon fiber (CFRP) and painted sheet metal without treatment of the surface. We are going to present first measurement results about the accuracy and the measurement uncertainty of this new measurement principle.

9489-16, Session 5

Terahertz reflection interferometry for automobile paint layer thickness measurement

Aunik K. Rahman, Applied Research & Photonics, Inc. (United States); Kenneth B. Tator, KTA-Tator, Inc. (United States); Anis Rahman, Applied Research & Photonics, Inc. (United States)

Non-destructive terahertz reflectometry [1] offers many advantages for sub-surface inspection such as interrogation of hidden defects and measurement of under-layer thicknesses. In this paper we describe a terahertz reflection interferometry (TRI) technique for non-contact measurement of paint panels where the paint is comprised of different layers of primer, basecoat, topcoat and clearcoat. Terahertz interferograms were generated by reflection from different layers of a paint panel on a metallic substrate. These interferograms' spacing separation arising from the delay-time response of respective layers, allows one to model the thickness of the individual layers. An angular scan demonstrates that the interferograms are more pronounced at certain angles than others. This "optimum" angle is also a function of different paint and substrate combinations. An automated scanning algorithm helps visualize the evolution of the interferograms as a function of angle and also enables the identification of optimum reflection angles for a given paint-substrate combination. Additionally, scanning at different points on a substrate reveals that there are observable variations from one point to another of the same panel over its entire surface area. This ability may be used as a quality control tool in the production line. Details of the procedure will be discussed, and data will be presented.

[1] Anis Rahman and Aunik Rahman, "Terahertz reflectometry of multi-layered paint thicknesses and estimation of particle sizes," CLEO: Applications and Technology, High Performance Optical Measurement (AW3H), San Jose, California, United States, June 8-13, 2014, ISBN: 978-1-55752-999-2. http://dx.doi.org/10.1364/CLEO_AT.2014.AW3H.4

9489-17, Session 5

Quantitative imaging of open-circuit voltage in opto-electronic devices with nanoscale resolution

Elizabeth Tennyson, Joseph Garrett, Univ. of Maryland, College Park (United States); Jesse A. Frantz, Jason D. Myers, Robel Y. Bekele, U.S. Naval Research Lab. (United States); Jasbinder S. Sanghera, Univ. Research Foundation (United States) and U.S. Naval Research Lab. (United States); Jeremy N. Munday, Marina S. Leite, Univ. of Maryland, College Park (United States)

One key parameter to evaluate the performance of opto-electronic devices is the open circuit voltage (Voc). For photovoltaics, the Voc dictates the power conversion efficiency, which is an indirect measurement of charge carrier recombination within the material. Identifying and spatially resolving where the recombination processes occur within micron-structured photovoltaics is crucial to the design of next generation solar cells. Presently, one major limiting factor of polycrystalline solar cells is the non-radiative recombination that stems from defects and grain interfaces within the semiconductor materials. Suppressing these processes can improve device performance significantly. Nevertheless, current measuring methods have been unable to probe the Voc with high spatial resolution. We present a novel imaging tool to resolve the Voc of opto-electronic devices with nanoscale resolution based on illuminated-Kelvin probe force microscopy [1]. This non-destructive approach operates at ambient environment, and only requires partially processed devices. The difference between the illuminated and dark surface voltage signals is proportional to the Fermi-level splitting of the p-n junction within the semiconductor, which is equal to the voltage generated by the device. We demonstrate the versatility of our new measurement technique when applied to different solar cell materials, including polycrystalline devices for lightweight, low-cost and high-efficiency photovoltaics. Further, we map the ideality factor of the devices with high spatial resolution, and identify the correlation between the structural properties of the grains and interfaces and the local Voc in different devices. Our metrology can be applied to a wide range of devices, including infrared sensors and high-power wide bandgap detectors.

[1] Tennyson, E.M et al. Imaging Open-Circuit Voltage in Solar Cells with Nanoscale Resolution. In Review

9489-18, Session 5

Application of holographic interferometry to in-plane and out-of-plane misalignment and deformation measurements in packaging applications

Vladimir V. Nikulin, Rahul M. Khandekar, Vijit Bedi, Binghamton Univ. (United States)

Packaging of electronic and photonic components requires high accuracy, which needs to be verified in the process of manufacturing and testing. Since very small misalignments and/or deformations can lead to unacceptable performance, a measurement approach is needed that would reveal displacements as small as a few tens of nanometers or less. In addition, misalignments and deformations occur both in the out-of-plane and in-plane directions, which may be very difficult to separate from each other. It was previously demonstrated that the two types of measurements can be implemented with different approaches: holographic interferometry for out-of-plane and moiré interferometry for in-plane, but it is very desirable to have a single system with sufficient accuracy in both lateral and longitudinal directions. An optical technique developed by our group and presented in this paper is based on a holographic approach and combines the principles of holographic interferometry and phase modulating adaptive optics that could provide simultaneous in-plane and out-of-plane measurements with high accuracy.

9489-19, Session 5

Real-time and uniaxial microscopic measurement of 3D profile by polarization grating

Yukitoshi Otani, Shuhei Shibata, Daisuke Barada, Utsunomiya Univ. (Japan)

An optical three-dimensional microscopic surface measurement has an advantage for non-contact, non-destructive and short measuring time. Many methods of stereo method such as a moiré and a grating projection are proposed. However these methods are difficult to apply a deep hole or steep height because intensity of bottom surface cannot be captured in the area of shadow portion. To overcome this drawback, a method of uniaxial measurement for three-dimensional surface on a microscopy is proposed by detecting a distance from contrast variation.

A spiral-polarization grating for contrast detection is projected onto a sample using a quarter wave plate and a spatial light modulator (SLM).

Intensity reflected from the sample is detected by a polarization camera, which is made with pixel polarizers attached on a CCD sensor. The azimuthal directions of pixel polarizer array are composed to 0°, 45°, 90° and 135°., so contrast of projected sinusoidal pattern onto sample is analyzed real-time by 4 stepping phase-shifting method. The contrast distribution is approximated the Gauss distribution along depth direction. It can be easily to fit the Gauss function measured in advance. The three-dimensional coordinate is calculated from a relationship Gauss distribution and measuring contrast. We propose real- time and uniaxial three-dimensional surface measurement on a microscopy using polarization grating controlled by a spatial light modulator.

9489-20, Session 5

3D position tracking for borescope inspections

Kevin G. Harding, GE Global Research (United States); Yong Yang, GE Global Research (China); Guiju Song, GE Global Research (United States)

Service providers perform regular borescope inspection of field products to ensuresystem performance and prevent accidents. A full borescope inspection for large equipment usually takes several days to cover every region of interest in the turbine. One of the challenges that causes this long inspection time is the difficulty in navigating the borescope tip to some position of interest and aiming the view of the borescope in given direction. The image from the borescope tip is the only information available to the operator to judge the position of tip. In some cases, the operator can get lost due to the limited field-of-view and illumination provided by the borescope. It is very hard to tell the borescope tip position from one borescope image. This increases the difficulty of correlating the inspection results obtained at different times that might be used to predict potential machineryfailure. This paper discusses various methods that have been investigated for 3D borescope tracking and presents a new approach using a shape sensor integrated in the borescope tube used with image based location determination to determine the position of the borescope tip during inspections. The shape sensor provides a real time estimate of the borescope tip position and orientation then the image based analysis uses the part CAD model to fine tune this position information. The tracking result can provide better information of the tip position for the operator. This enhanced position information can be used to better monitor defect changes over time by comparing the inspection result at different times in the parts lifetime.

9489-21, Session 5

Small hole inner profile measurement method

Yi Liao, Kevin G. Harding, Rajesh Ramamurthy, GE Global Research (United States)

It is very difficult to measure the inner profile geometry of small holes of less than a millimeter in size, yet that geometry may be important for some manufacturing operations. This paper will present a method to measure key dimensional parameters of small holes used in systems such as for turbo-machinery. Precision shaped holes can consist of a hole at some angle to the surface of the part and an area around the entrance to the hole for the purpose of diffusing the air or lubricant across the surface of the part to achieve the most effective performance. The drive towards smaller and more complex hole geometries means that previous methods such as touch probes do not provide a good mapping in a time that can be used as part of production. The advanced designs of the holes means simple pin gages do not provide enough information. This paper will discuss tests of various methods considered for mapping small hole inner diameters, and present results of the use of depth from defocus as a possible solution.

9489-22, Session 5

High contrast imaging in the presence of a bright background

Harbans S. Dhadwal, Jahangir Rastegar, Dake Feng, Omnitek Partners, LLC (United States)

In recent years, considerable attention and resources have been directed at the development of scanning endoscopes that can be used to access human organs with ease and transport high resolution in vivo images. While lateral and axial resolutions have seen tremendous increases, insignificant advancement has been made toward improving contrast of images recorded under bright field conditions, which are unavoidable in areas of in vivo medical imaging, such as, laparoscopy surgery and endomicroscopy, visual inspection of nano-scale devices and the like.

The key to improving image contrast is to minimize the bright background prior to detection and conversion to a digital image. We have developed an optical solution for overcoming these limitations by processing the image in the optical domain. In particular, the composite image, which comprises of the object and the background signal, is processed in the optical domain prior electronic detection. The background signal, which has a very narrow frequency bandwidth centered at the origin, is separated from the object distribution by masking the high energy at the origin of the spatial frequency plane. Current digital signal processing methods are not able to achieve significant improvements in image contrast due to the poor dynamic range of the electronic image, which is dominated by the bright field signal. Thus, the proposed method will enable the use of high illumination, which is critical to obtaining high quality images in voids and similar hard to illuminate volumes.

In general, the mask will be an inverse filter designed to cancel the effects of the background signal. The final image on the detector plane will correspond directly to the original object function, with the highest contrast possible. We have incorporated the above high pass filter into a compact imaging system designed for collecting images of features etched into highly reflective substrates. The results show considerable enhancement of the image contrast.

9489-23, Session PTue

The Omni-directional Image Assisted Optical Surveillance System.

Yung-Hsiang Chen, National Applied Research Labs. (Taiwan) and National Tsing Hua Univ. (Taiwan); Chi-Hung Hwang, National Applied Research Labs. (Taiwan); Wei-Chung Wang, National Tsing Hua Univ. (Taiwan); Chun-Fu Lin, National Applied Research Labs. (Taiwan)

This paper presents a high resolution optical surveillance system with which integrated an omni-directional imager as an event finder/ system trigger. The omni-directional optics, a fish-eye camera in this study, provides a wider field of view (FOV) which can monitor widely range continuously without scanning mechanism but offers sufficient information which includes sign of field event and direction and then drive high resolution surveillance camera for detail imaging. To archive an optical triggering surveillance system, the scale-invariant feature transform (SIFT) is implemented to detect features both from images taken by omni-directional imager and the high resolution surveillance system. Considering the FOV of high resolution surveillance system is narrow, to ensure the pointing of high resolution surveillance camera, feature matching is also implemented in this system to identify the images obtained by high resolution surveillance system are identical to the existing omni-directional image obtained from fish-eye camera. This provides a robust and accurate solution to the problem of optical radar surveillance system localization in unknown environments. An experiment is performed on outdoor image sequences with demonstrating the efficiency of our algorithm.

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9490-1, Session 1

Non-invasive disease diagnostics based on oral biospecimens: lessons learned and future directions *(Invited Paper)*

Isaac R. Rodriguez-Chavez, National Institute of Dental and Craniofacial Research (United States)

The burden of oral diseases globally drives the increased demand for superior bio-sensing technologies applied to rapid tests (RTs) and point-of-care-devices (POCs). Clinical diagnosis, patient care, disease management and monitoring epidemics are a few of the examples where fast, robust and accurate bio-sensing for global human disease diagnosis is essential. Better diagnosis save, extend and improve lives. The efficiency and success of the "test and treat" clinical approach to manage diseases depends on the development and application of these state-of-the-art emerging, fast and automated bio-sensing technologies. Thus, it is important to continue developing the next-generation of RTs and POCs with superior technical performance compared to existing diagnostic tools. These novel diagnostic approaches also tend to minimize costs and the invasiveness of specimen collection as well as they simplify the number of steps involved in its performance and the time to yield diagnostic results. This talk will discuss current gaps and the improvements made in the field of RTs and POCs coupled to the latest bio-sensing approaches when using oral biospecimens. It will also review future trends in the bio-sensing diagnostics field.

9490-2, Session 1

The human saliva proteome: overview and emerging methods for characterization *(Invited Paper)*

Timothy J. Griffin, Univ. of Minnesota (United States)

Human saliva holds tremendous potential for transforming disease and health diagnostics given its richness of molecular information and non-invasive collection. Enumerating its molecular constituents is an important first step towards reaching this potential. Among the molecules in saliva, proteins and peptides arguably have the most value: they can directly indicate biochemical functions linked to a health condition/disease state, and they are attractive targets for biomarker assay development. However, cataloging and defining the human salivary proteome is challenging given the dynamic, chemically heterogeneous and complex nature of the system. Presented here will be a summary of communal efforts to meet this challenge, focusing on the current snapshot of the human salivary protein catalog, and including efforts to characterize the chemical heterogeneity of the proteome (e.g. post-translational modifications). A summary of work aimed at identifying the contribution from the oral microbiome to the human saliva proteome will also be presented. Implications of these efforts to characterize the salivary proteome in the context of disease diagnostics will be discussed. Emphasis will also be given to describing emerging methods for salivary proteomic characterization, including methods integrating genomic and proteomic data (proteogenomics and metaproteomics) and also new instrumental methods, such as data independent approaches for hypothesis-driven proteomics.

9490-3, Session 1

Comparison between oral and salivary diagnostics *(Invited Paper)*

J. Marques, Univ. de Lisbon (Portugal); Patricia Corby, C. Barber, William R. Abrams, New York Univ. College of Dentistry (United States); Daniel Malamud, New York Univ. (United States)

The field of "salivary diagnostics" includes studies utilizing samples obtained from a variety of sources within the oral cavity. These samples include; whole unstimulated saliva, stimulated whole saliva, duct saliva from the parotid, submandibular/sublingual glands or minor salivary glands, swabs of the buccal mucosa, tongue or tonsils, and gingival crevicular fluid. Many publications merely state "we collected saliva from subjects" without describing the process or source of the saliva. Additional factors that need to be documented include the time of day of the collection, the method used to stimulate and collect the fluid, and how much fluid is being collected. The handling of the oral fluid post-collection is critical and may include protease inhibitors, nuclease inhibitors, centrifugation, and cold or frozen storage prior to assay. In an effort to create a standard protocol for determining a biomarker's origin we carried out a pilot study collecting fluid from 5 different sites in the oral cavity and monitoring the concentrations of pro- and anti-inflammatory cytokines as detected with MesoScaleDiscovery (MSD) plates. Our data suggest that 3 of the cytokines are primarily derived from the submandibular gland, while 7 of the cytokines come from a source other than the major salivary glands such as the minor salivary glands, gingival crevicular fluid, or cells in the oral mucosae.

9490-4, Session 1

Saliva fluid considerations in oral diagnostics

Eva J. Helmerhorst, Boston Univ. (United States)

Salivary diagnostics has received a vast amount of attention ever since it was discovered that saliva contains biomarkers for disease processes ongoing elsewhere in the human body. Human saliva is easy to collect by non-invasive means. While these are clear advantages over the collection of human blood, saliva is, in contrast to blood (serum) a more complex body fluid to be stored and analyzed. It is comprised of water, ions, and proteins, that are bacterial- and human cell derived. The exocrine secretions produced by major and minor salivary glands contain a wide variety of secretory proteins including highly glycosylated mucins. The non-exocrine constituents are oral microorganisms, desquamated epithelial cells, human immune cells, and gingival crevicular fluid, a serum-like transudate emanating from the gingival sulcus. While the complexity of saliva offers tremendous opportunities for saliva diagnostics and biomarker discovery, it also poses additional challenges. These are related to the structural stability of biomarkers in oral fluid, the dilution of biomarker components of interest, and the complexation of biomarkers to other salivary constituents. We will touch upon these in this presentation and propose methods that can improve reliability of outcomes in diagnostic investigations. Studies are supported by NIH/NIAID grants AI087803 and AI101067.

9490-5, Session 1

Addressing the challenges of system integration for non-invasive diagnostics

Vincent Gau, Genefluidics (United States)

Many components in biological matrices influence the result of an analysis, affecting assay sensitivity and reproducibility. Matrix effects are complex and system specific. Each biological matrix presents different management challenges, and each type of analytical method is affected by matrix components differently. Therefore we streamline the raw specimen processing procedure into our integrated system to remove the blood matrix and recover all pathogens through a fully integrated microfluidic cartridge. In the past 12 years, GeneFluidics has developed, demonstrated and published an electrochemical biosensor for rapid infection diagnostics directly from urine, saliva and blood without target purification or amplification to establish three distinct sets of species-specific probe pairs optimized for hybridization temperatures at room temperature (RT), 37ºC and 65 ºC. Our microfluidic cartridge development including a pathogen identification (PID) and antimicrobial susceptibility testing (AST) cartridge and a salivary diagnostic oral cancer cartridge with a multiplexed RNA/immunoassay panel. To facilitate the product commercialization, which focuses on the development and validation of a fully integrated cartridge, all system control and reagent delivery can be provided by our current robotic lab automation system. The clinical feasibility studies are performed with a compact electrochemical detection reader, and system control and reagent delivery replaced by a fluidic manifold with results viewable on a smartphone or laptop.

9490-6, Session 1

Saliva-based molecular diagnostics of HPV

Jennifer Webster-Cyriaque, The Univ. of North Carolina at Chapel Hill (United States); William Seaman, Univ. of North Carolina at Chapel Hill (United States)

Human papillomaviruses (HPV) are tumorviruses that are shed into oral secretions. While over 150 different types of HPV have been identified, HPV16 and 18 are the most common oncogenic types, and HPV6 and 11 are most commonly associated with warts. While other quantitative PCR (qPCR) can be used to detect oncogenic HPV, there was not an assay that could between these four types that are thought to cause the majority of HPV-associated disease. A single tube multiplex assay qPCR assay was developed that allowed distinction, detection and quantitation using type-specific primer pairs and TaqMan probes. A Sybr Green-based qPCR assay using degenerate primers targeted the conserved E1 region of all HPVs. qPCR assays were applied in the context of clinical trials to determine the effect of HIV treatment (ART) on HPV shedding. There was good agreement between the ability of the qPCR assays to identify HPV types in oral secretions and with sequenced based results. 19% had at least one subtype of oral HPV DNA present before starting ART and 25% had at least one subtype present after ART initiation. Post ART, 20% had a new HPV subtype present in throat wash that was not identified in the specimens obtained before initiating ART. 22% of subjects persisted in shedding at least one of the prevalent subtypes. These qPCR assays were effective in the evaluation of the consequence of HIV therapy to oral HPV pathogenesis.

9490-7, Session 1

Next generation saliva diagnostics: host response biomarkers for HIV diagnostics

Sarka O. Southern, Gaia Medical Institute (United States); Jennifer Webster-Cyriaque, The Univ. of North Carolina at Chapel Hill (United States); Martin Gleeson, Genalyte, Inc. (United States)

Our goal is to develop Next Generation rapid disposable tests for priority infectious diseases such as HIV and Ebola. The Next Generation tests will detect the pathogen and host response biomarkers in saliva using a simple point-of-care device. The Next Generation tests will facilitate routine, stigma-free screening and disease management outside of traditional healthcare settings, in community clinics and field settings. Based on CDC statistics, about 1.2 million people in the US are living with HIV. Nearly 1 in 5 people with HIV don't know they are infected, don't get HIV medical care, and can pass the virus on to others without knowing it. Only 28% of people with HIV are taking HIV medicine regularly and have their virus under control. Routine HIV screening is needed to limit the spread of HIV, and to provide individualized therapeutic monitoring of HIV/AIDS patients treated with antiretrovirals. This year, the world is facing the biggest and most complex Ebola outbreak in history. Coordinated public health actions are essential to stop and reverse the spread of Ebola. To stop the spread of Ebola from West Africa and within USA there is an urgent need to screen large numbers of people to determine whether someone has Ebola and needs to be treated before developing symptoms and spreading the disease.

9490-8, Session 2

Early predictive markers of organ injury and toxicity

Danielle L. Ippolito, U.S. Army Ctr. for Environmental Health Research (United States); Mohamed D. M. AbdulHameed, Gregory J. Tawa, BHSAI (United States); John A. Lewis, U.S. Army Ctr. for Environmental Health Research (United States); Christine E. Baer, EXCET, Inc. (United States); Bonna C. Donald, Oak Ridge Institute for Science and Education (United States); Anders Wallqvist, BHSAI (United States); Jonathan D. Stallings, U.S. Army Ctr. for Environmental Health Research (United States)

Technological solutions are needed to rapidly assess organ injury with rapid, point-of-care diagnostics. Identifying early predictive markers of multiple organ injury which can be multiplexed into a portable device for emergency medical response teams represents a critical barrier to providing the tools needed for early diagnosis. In this study, we describe computational methods for identifying biomarkers of end organ injury. We present validation studies in rodents for testing the predictive power of the novel biomarkers in toxic chemical injury. Biomarkers of drug-induced liver injury were identified by literature searches and analysis of a large repository of gene expression data, the DrugMatrix database. Protein and microRNA levels in plasma or urine were correlated with gene expression levels in tissue and/or histopathology (steatosis, fibrosis, inflammation, and necrosis). Gene, clinical chemistry, microRNA, and protein expression analysis indicated that panels of liver injury biomarkers of liver injury were better predictors than single literature-derived indicators alone. The combination of chemistries—small molecules, proteins, and nucleic acids—coupled with the differences in biofluid (serum and urine) present challenges for developing multiplexed technologies to detect organ injury.

Disclaimer: Research was conducted in compliance with the Animal Welfare Act and all other Federal requirements. The views expressed are those of the authors and do not constitute endorsement by the US Army. This research was supported in part by an appointment to the Postgraduate Research Participation Program at the USACEHR administered by the ORISE through an interagency agreement between the US DOE and USAMRMC.

9490-9, Session 2

Detecting biotargets and drugs from blood, urine and saliva *(Invited Paper)*

Utkan Demirci, Stanford Univ. School of Medicine (United States)

Micro/nano-scale technologies provide a notable impact on medicine and biology in the areas of cell manipulation, regenerative medicine, diagnostics and monitoring. In our laboratories, we create solutions to address the real world problems, which are currently observed at the clinical settings. By focusing on global health problems, in this talk, we will present an overview of our recent developed platform technologies in point-of-care (POC)

and primary care settings for detection, isolation and quantification of multiple biotargets such as eukaryotic cells, bacteria, viruses and protein biomarkers from unprocessed bodily fluids including saliva, urine, whole blood and serum. For instance, cancer and infectious diseases are the leading causes of death and pose significant burden on global healthcare, especially in developing countries. In 2008, there were 7.6 million cancer deaths worldwide, representing 64% of the deaths in developing countries. Similarly, HIV infects 35 million people, and HIV/AIDS has killed more than 25 million people worldwide. In HIV/AIDS patients, coinfection with other viruses, such as Kaposi's sarcoma-associated herpes virus (KSHV), can lead to the development of Kaposi sarcoma (KS) tumors, which is the leading AIDS malignancy. KS frequently occurs in the oral cavity and shed in saliva. KSHV also is the etiologic agent of primary effusion lymphoma (PEL) and is tightly linked with multicentric Castleman's disease, an aggressive lymphoproliferative disorder. Currently, there are no specific or highly effective treatment options for KS, PEL or multicentric Castleman's disease. The development of inexpensive, rapid detection of KSHV from blood and noninvasive biospecimens such as saliva is important for several reasons. Further, antiepileptic drugs (AEDs) are the mainstay of treatment for persons with epilepsy (PWE). However, as many as 2 out of 3 PWE suffer from recurrent seizures or AED-related side effects. In either case, the optimization of AED dosages is clinically important and often guided by measuring AED serum concentrations. However, there are only lab-based platforms available. Thus, there is a great need for simple, rapid, reliable and disposable tests for AED measurements that can be performed at the doctor's office or by the patient or a family member at home. To address these specific clinical and technological challenges, we developed platform technologies that provide detection limits down to femtogram/mL level from biologically relevant samples as well as saliva samples with a broad linear dynamic range. Our innovative technologies could direct our future creating broadly applicable platforms for scientific discovery, providing clinical solutions for resource-constrained settings in the developing world as well as for primary care settings in the developed world.

9490-10, Session 2

Imaging-based rapid test and assay reader with trans-visual sensitivity

Onur Mudanyali, Neven Karlovac, Holomic (United States)

Rapid diagnostics Tests (i.e., lateral flow and flow through immunoassays) indicate the presence of the diseases, threats and contamination by color/contrast changes and variations. Exhibiting important opportunities for medical and environmental diagnostics applications, these immunoassays suffer from limited sensitivity (i.e., limit of detection - LOD) and repeatability (i.e., high coefficient of variation - CV). Therefore, their interpretation by humans and/or digital devices is prone to critical errors. To address this important need for accurate and reliable test evaluation, we developed a smartphone-based reader platform that provides an exceptional performance, achieving a very low CV (down to 0.1%) and trans-visual sensitivity to significantly improve the LOD of immunoassays.

The reader utilizes opto-electro-mechanical hardware attachments (e.g., for chromatographic and fluorescent imaging) and a smartphone application to digitally image, analyze and interpret the assays using a custom-developed image processing algorithm with dynamic feature extraction and background estimation. The smartphone attachment, enclosing all opto-electronics components, enables the necessary illumination and enhancement for high-performance image analysis and also mechanically accommodates the tests/assays without using any external components or adapters. Moreover, we also developed a software suit (i.e., Holomic Test Developer) for the technical investigation of assay behavior during the research and development stages as well as configuration/calibration of smartphone readers to work with new test/lot types without any software and hardware adaptations.

This digital platform may provide a powerful tool to not only read and interpret rapid tests and immunoassays but also improve their performance to a level beyond the ability of human vision.

9490-11, Session 2

Multiplex on-chip detection of pathogen biomarkers in human saliva using silicon photonic microring resonators

Martin A. Gleeson, Genalyte, Inc. (United States)

Genalyte has developed a silicon photonic chip diagnostics platform (MaverickTM) for rapid detection of multiple biological analytes from a drop of sample. We present here result generated detecting pathogen antigens, and immune response antibodies in saliva. The core of the technology is a silicon microchip, on the surface of which we pattern 64 microscopic ring resonators covered by a single microfluidic channel. The rings are individually functionalized to bind antigens (to detect infectious agents or toxins directly), antibodies (to detect immune response), or other biomarkers of infection in a sample that is pumped through the channel over the rings. The frequency of each ring's optical resonance is exquisitely sensitive to the mass of bound analyte. A laser in the Maverick instrument interrogates 128 rings (two patient samples) simultaneously to quantify the presence of analytes. Currently, each assay is performed in quadruplicate, providing 15 multiplexed assays plus 1 control. The chips are packaged into a consumable cartridge that measures 24 patient samples (for Maverick). A 96 well plate with foil cover holds the reagents for all the tests, including 24 wells with a buffer solution, into which the operator loads the samples. The user need only collect a few drops of sample, saliva or blood, transfer them to the sample well, insert the measurement cartridge and the well plate into the unit, and press start. The instrument performs all fluid operations internally, connecting dedicated probes from the measurement cartridge to the appropriate wells in the plate and pumping the sample and reagents through the microfluidic channels on the sensor chips as required by the assay protocol.

9490-12, Session 2

Optical biosensor technologies for molecular diagnostics at the point-of-care *(Invited Paper)*

Joerg M. Schotter, Stefan Schrittwieser, Paul Muellner, Eva Melnik, Rainer Hainberger, AIT Austrian Institute of Technology GmbH (Austria); Guenther Koppitsch, Franz Schrank, ams AG (Austria); Katerina Soulantika, Sergio Lentijo-Mozo, Institut National des Sciences Appliquées de Toulouse (France) and Lab. de Photonique et de Nanostructures, CNRS, Univ. de Toulouse (France); Beatriz Pelaz, Wolfgang J. Parak, Philipps-Univ. Marburg (Germany); Frank Ludwig, Jan Dieckhoff, Technische Univ. Braunschweig (Germany)

Label-free optical schemes for molecular biosensing hold a strong promise for point-of-care applications in medical research and diagnostics. Apart from diagnostic requirements in terms of sensitivity, specificity, and multiplexing capability, also other aspects such as ease of use and manufacturability have to be considered in order to pave the way to a practical implementation.

We present integrated optical waveguide as well as magnetic nanoparticle based molecular biosensor concepts that address these aspects. The integrated optical waveguide devices are based on low-loss photonic wires made of silicon nitride deposited by a CMOS compatible plasma-enhanced chemical vapor deposition (PECVD) process that allows for backend integration of waveguides on optoelectronic CMOS chips. The molecular detection principle relies on evanescent wave sensing in the 0.85 μm wavelength regime by means of Mach-Zehnder interferometers, which enables on-chip integration of silicon photodiodes and, thus, the realization of system-on-chip solutions.

Our nanoparticle-based approach is based on optical observation of the

dynamic response of functionalized magnetic-core/noble-metal-shell nanorods ('nanoprobes') to an externally applied time-varying magnetic field. As target molecules specifically bind to the surface of the nanoprobes, the observed dynamics of the nanoprobes changes, and the concentration of target molecules in the sample solution can be quantified. This approach is suitable for dynamic real-time measurements and only requires minimal sample preparation, thus presenting a highly promising point-of-care diagnostic system. To that end, we show comparative measurements for the detection of the breast cancer biomarker HER2 from both serum and saliva samples.

9490-29, Session 2

A systems biology approach to heat stress, heat injury and heat stoke *(Invited Paper)*

Jonathan D. Stallings, Danielle L. Ippolito, U.S. Army Ctr. for Environmental Health Research (United States)

Heat illness is a major source of disease non-battle injuries in both deployed and training settings. Developing tools to help leaders enhance performance while reducing the risk of injury is paramount. Here, we describe a systems biology approach to heat stress in order to develop a 3-dimensional (3D) realistic thermoregulation model, identify the molecular basis of injury, and characterize associated pathways and biomarkers. We discuss the implication of our previous work, future directions, and the type of tools that will be necessary to enhance force health protection in the future.

Disclaimer: Research was conducted in compliance with the Animal Welfare Act and all other Federal requirements. The views expressed are those of the authors and do not constitute endorsement by the US Army.

9490-14, Session 3

Lab-on-a-chip enabled HLA diagnostic: combined sample preparation and real time PCR for HLA-b27 diagnosis *(Invited Paper)*

Claudia Gärtner, Holger Becker, Richard Klemm, Sebastian Schattschneider, Nadine Hlawatsch, Christian Moche, microfluidic ChipShop GmbH (Germany); Rainer Frank, Andreas Willems, Inno-Train Diagnostik GmbH (Germany)

In case of transplantation, the identification of special metabolic diseases like coeliac disease or autoimmune diseases HLA (human leucocyte antigen) typing is of interest. The special protein complex HLA-B27 for instance is associated with autoimmune diseases like rheumatoid arthritis on the one hand side, but also binds very efficiently viral antigens leading e.g. of a significantly later manifestation of AIDS after the HIV infection of HLA-B27 positive persons compared to HLA-B27 negative ones.

A fast and easy analysis of these samples is of interest, allowing the physicians a direct diagnosis during one visit at the doctor's side. This can only be realized if besides sample taking and the transfer in the analytical instruments all steps are carried out without manual intervention within a limited amount of time not exceeding 60 minutes, preferably below 45 min.

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.

9490-15, Session 3

A graphene-modified cellulose paper microchip for HIV detection

Mohammadali Safavieh, Brigham and Women's Hospital (United States); Sultan Khetani, Vivasvat Kaul, Brigham and Women's Hospital (United States); Daniel R. Kuritzkes, Hadi Shafiee, Brigham and Women's Hospital (United States)

Human immunodeficiency virus (HIV) takes the lives of more than 1.5 million people per year and cumulatively has caused more than 39 million deaths since 1981. Antiretroviral therapy (ART) has shown a great promise in effectively controlling HIV worldwide and ART expansion in developing countries has reduced mortality by more than 5 million deaths. However, achieving long-term ART-free HIV remission or functional cure requires halting viral replication and eliminating latently infected cellular reservoirs. Although ART stops ongoing viral replication by blocking non-infected susceptible cells from becoming infected, it cannot completely eradicate HIV as it cannot identify and eliminate cellular reservoirs harboring an integrated HIV genome that do not produce viral proteins. Accurate detection and elimination of these latent reservoirs is critical as ART can be discontinued only if these latent cells are completely eradicated. Morphological and structural changes in the genome structure, cell membrane, and cytoplasm due to HIV infection may change the electrical fingerprint of latently infected CD4+ T cells. This change in electrical response of the cells can be a powerful and sensitive tool to identify and sort these rare reservoirs in whole blood or tissue samples utilizing microfluidic technology. Our preliminary results show that the electrical response of cell lines representing latently viral-infected cells and non-infected cells is significantly different. Early detection of HIV infection and ART failure through viral load counting is also another major challenge in HIV management in resource-limited settings. The current viral load technologies in developed countries are time-consuming, laboratory-based, expensive, and labor-intensive and cannot be implemented in developing countries. We have developed biosensing microchip technologies for virus detection and counting in fingerprick volume of biological samples including plasma and saliva using electrical and optical modalities.

9490-16, Session 3

Rapid detection of ebola virus in immunofiltration lab on chip system

Peter Miethe, fzmb GmbH (Germany); Claudia Gärtner, microfluidic ChipShop GmbH (Germany); Dominik Gary, fzmb GmbH (Germany); Nadine Hlawatsch, microfluidic ChipShop GmbH (Germany)

Diagnostics for ebola virus infection are based mainly on reverse-transcription polymerase chain reaction (RT-PCR) technology and antigen-capture ELISA, which can be supplemented with antibody-detection assays. These assays are established in national and international reference laboratories equipped with the necessary biocontainment. However, rapid and less-sophisticated methods are urgently needed for diagnostics under

rural or technically demanding conditions in the field.

We developed a rapid, safe and reliable antigen-detection assay for use with blood and urine samples. The assay is based on the immunofiltration technology that uses previously characterized EBOV-specific monoclonal antibodies (MAbs) directed against matrix protein VP40 of all known EBOV species and that previously had been found to work in a conventional ELISA.

We have integrated all assay steps an lab on chip device. The core elements are micro porous polyethylene sinterbodies with immobilize capture antibodies, reference ligands and negative control. The second antibody is biotin labeled and used for photometric detection of the bound viral antigen by streptavidin–horseradish peroxidase (HRP) and TMB (tetramethylbenzidine). All necessary reagents (conjugates, substrates) are stored in dry form in micro cavities. The lab on chip systems is processed with a micro pipetting system. Typical assays are performed within 15 minutes. The detection limit achieved for ebola virus is in the order of 102 CFU/m corresponding to 5?103 TICD50.

9490-17, Session 3

Low cost molecular diagnostics for cancer and infectious disease

Catherine Klapperich, Boston Univ. (United States)

Recent advances in microfluidic and paperfluidic devices have brought molecular diagnostics closer to translation into the clinic than ever before. Many in the field of device and diagnostic design have shifted from developing novel components to designing whole devices, with an eye towards usability and robustness. These are positive developments. In our laboratory, we integrate several new approaches to make devices for use in resource limited settings. Our recent work has focused on infectious diseases including HIV, infectious diarrhea, and other sexually transmitted infections. A test for HPV, important in the early detection of both cervical cancer and head and neck cancers is currently under development. I will present data from this work and a summary of the point-of-care (POC) diagnostic work funded by the NIBIB Center for Future Technologies in Cancer Care (www.bu.edu/cftcc).

9490-18, Session 3

PANDAA: rapid sensitive detection of highly polymorphic pathogens and quantification of drug resistance

Iain J. MacLeod, Harvard School of Public Health (United States) and Botswana-Harvard AIDS Institute (Botswana) and Aldatu Biosciences (United States); Christopher F. Rowley, Harvard School of Public Health (United States) and Botswana-Harvard AIDS Institute (Botswana) and Beth Israel Deaconess Medical Ctr. (United States); David M. Raiser, Aldatu Biosciences (United States); M. Essex, Harvard School of Public Health (United States) and Botswana-Harvard AIDS Institute (Botswana)

The WHO goal of expanding HIV antiretroviral therapy (ART) access to 15 million people by 2015 could be crippled by increases in acquired and transmitted HIV drug resistance due to inadequate patient monitoring. Current resistance testing is cost-prohibitive in low- and middle-income countries leading to acquisition of additional resistance, further reducing future therapeutic options. A simple, rapid, and affordable HIV drug resistance test stands to radically improve this treatment paradigm by facilitating informed clinical decision-making throughout sub-Saharan Africa. Targeted point mutation assays (PMAs) – such as quantitative real-time PCR (qPCR) – offer one such possible approach to drug resistance testing. However, PMAs are significantly constrained by the presence of secondary mutations (i.e. proximal nucleotide changes unrelated to the mutation of interest) that are frequently found in highly polymorphic pathogens. Previous attempts to use probe-based qPCR to detect single nucleotide changes associated with drug resistance have failed due to the highly polymorphic nature of HIV. Pan Degenerate Amplification and Adaptation (PANDAA) enables qPCR to be used for sensitive, high-throughput HIV genotypic resistance testing in a subtype-independent manner. By adapting the probe-binding site in the HIV genome, thereby compensating for secondary mutations that would otherwise abrogate probe binding, PANDAA can overcome the long-standing technical challenges associated with the genomic variability of highly polymorphic pathogens. By adapting qPCR for routine HIV drug resistance diagnostics for the first time, PANDAA represents a significant advancement that allows the simultaneous detection of multiple drug resistance mutations with considerable speed, sensitivity, and cost advantages over existing methods.

9490-19, Session 3

Next-generation DNA in pathogen detection, surveillance, and CLIA-waivable diagnostics

Steven A Benner, The Westheimer Institute for Science and Technology (United States); Hyo-Joong Kim, Firebird Biomolecular Sciences LLC (United States); Kristen B. Merritt, Zunyi Yang, D. Chris McLendon, Shuichi Hoshika, Foundation for Applied Molecular Evolution (United States); Daniel Hutter, Firebird Biomolecular Sciences LLC (United States)

Because of its “rule based” pairing (A pairs with T, G with C), DNA appears to be ideal as a scaffolding for constructing nanostructures, assembling enzymes for ordered and sequential transformation of organic molecules, or even for self-assembly of entire genetic constructs, from plasmids to chromosomes, to explore biomolecular mechanisms in normal and diseased biological function. Unfortunately, chemical realities make those rules imperfect, so imperfect that these (and other multiplexed tasks) simply cannot be done reliably. This talk will describe recent work that redesigns DNA mitigate various of its chemical imperfections. It will focus on artificially expanded genetic information systems (AEGIS). AEGIS is a species of DNA having extra nucleotide “letters” added to the four that are found naturally in DNA. AEGIS nucleobases pair with geometries closely similar to those in the standard Watson-Crick pair, but with hydrogen bonding patterns different from (and orthogonal to) hydrogen bonding patterns that join the natural A:T and G:C pairs. Thus, AEGIS DNA can be copied by engineered DNA polymerases, can support PCR, and can even direct translation to give proteins with extra amino acid “words”. Recent work using expanded synthetic DNA to diagnose diseases, assemble nanostructures, and create large genetic constructs will be discussed. Further, progress towards creating E. coli cells that are able to manage artificially expanded genetic alphabets will be described. Together, these illustrate how a fundamental and molecular re-design of natural living systems can provide a foundation for a “New Synthetic Biology”.

9490-20, Session 3

The Ad5 [E1-, E2b-]-based Vector: A New and Versatile Gene Delivery Platform

Frank Jones, Etubics Corporation (United States); Elizabeth Gabitzsch, Etubics Corp. (United States); Joseph P Balint Jr., Etubics Corporation (United States)

Recombinant vectors have been used in the settings of gene therapy, vaccination and immunotherapy but have encountered experimental and clinical challenges because they are recognized as foreign entities. Immunologic host recognition leads to a clearance of the vectors resulting in mitigation of the vaccination outcome. We have reported on a new vector platform, Ad5 [E1-, E2b-], an improved Ad5 vector which can deliver multiple disease gene targets. This vector platform can be utilized as an immunization modality to induce immune responses even in the presence of Ad5 immunity. At present we are focused on the immunization of and treatment of difficult to treat diseases. We have reported on immunization and immunotherapy of multiple infectious diseases such as HIV, influenza and various cancers. In a Phase I/II study employing Ad5 [E1-, E2b-]-CEA which expresses a modified carcinoembryonic antigen (CEA(6D)) transgene we treated patients with colorectal cancer. CEA-specific CMI responses were observed despite the presence of pre-existing Ad5 immunity. The median overall-survival of the patients treated was an encouraging 11 months. We have also reported on our Ad5 [E1-, E2b-]-E6/E7 immunotherapy in an HPV induced cancer model which induced immune responses and tumor clearance. HIV infected individuals have a high incidence of HPV induced cancers. Our Ebola and universal influenza vaccines are under development with encouraging results. The Ad5 [E1-, E2b-] platform is an improved vector technology with broad vaccination and immunotherapeutic application which holds promise in the treatment and prevention of many difficult to treat disease targets.

9490-21, Session 3

Nanopore sensing technology for single molecule and single cell analysis

MinJun Kim, Drexel Univ. (United States)

Solid state nanopores were developed almost a decade ago as an alternative to protein nanopores for next-generation sequencing of DNA molecules. In recent years, however, they have drawn significant attention as an analytical tool to study other nanoscale analytes. Compared to biological nanopores, solid-state nanopores are more robust and can be tuned in size and geometry to meet various requirements for a wide range of applications. A size scale that spans from single macro-molecules (<10 nm) to single-particle viruses (50-200 nm) and even single-cell microorganisms such as bacteria (1 - 2 μm) makes solid-state nanopores a powerful analytical tool for single-particle, single-molecule or single-cell research. In fact, nanopore can provide a unique opportunity to bridge the gap between single-molecule and single-cell research. In this presentation, we first review micro/nano-fabrication techniques to achieve a wide range of pore size and geometry and then discuss applications in sensing and biophysical analysis of single-molecules and single cells. Particularly, we will review our recent works on single-protein research including protein binding and protein-protein interactions as well as single-virus research for sensing human immunodeficiency virus (HIV) and study biophysical deformation of single viruses as they translocate through the pore.

9490-22, Session 3

Homogeneous biochemiluminescence assays for point of care use

X. James Li, Cellex, Inc. (United States)

An ideal diagnostic test for point of care use should be rapid, simple, easy-to-use, sensitive, specific and still affordable. It has been a challenge to develop assay technologies, which enable the development of POC tests that would meet all of these attributes. The homogeneous biochemiluminescence assay (HBA) technology was developed and used to develop several POC tests, including the QFlu Combo Test, which can simultaneously detect influenza virus and its resistance to Tamiflu, and QAR Test, which can detect antibiotic resistance of bacterial species caused by beta lactamase and its resistance to beta lactamase inhibitors. These POC tests are rapid (about 15 minutes), sensitive (femtomolar level), specific and affordable.

The HBA uses the well-known luciferin/luciferase system for detection of enzyme activities and resistance to enzyme inhibitors. We designed luciferin-containing substrates specific for marker enzymes. In the presence of the marker enzyme, the luciferin is freed and becomes a substrate of luciferase, leading to production of detectable light signal. A variation of the HBA technology enables detection of binding activities such as antigen-antibody binding. Thus, highly sensitive and easy-to-use immunoassays can also be developed using the HBA technology.

9490-23, Session 3

Advances in global health through sensing technologies

Jonathan C. Claussen, Iowa State Univ. (United States)

Diabetics are prone to having their blood sugar levels drop during exercise causing hypoglycemia. This sudden drop in blood glucose levels is difficult to self-diagnosis as fatigue and sweating, which are typical signs of hypoglycemia, are also common results of rigorous exercise. Therefore such rigorous exercise could lead diabetics to a severe hypoglycemic state, which can cause mental confusion, unconsciousness, or even seizures. In order to prevent severe hypoglycemia and help diabetics maintain their blood glucose levels during exercise, we have developed a printable-based glucose biosensor that can be incorporated into elastic bands and other clothing apparel. The electrodes of the glucose biosensor are comprised of graphene-based inks that are ink jet printed onto flexible clothing apparel. Enzymes are functionalized onto the graphene inks to functionalize the electrodes for selective glucose sensing. The sensitivity of the printed circuit to glucose is analyzed as well as the durability of the biosensor during flexed and un-flexed scenarios. These results demonstrate that electrochemical glucose biosensors could potentially be incorporated into clothing so that diabetics could non-invasively and continuously monitor their blood glucose levels during exercise. Furthermore, the use of ink jet printed inks circumvents the cost associated with conventional electrode designs that utilize photolithography to pattern surfaces with metal layers and chemical vapor deposition to grow graphene.

9490-24, Session PTue

Differential excitation spectroscopy for detection of industrial chemicals: benzene and chlorinated solvents

Boyd V. Hunter, Jason M. Cox, Kestrel Corp. (United States); Michael A. Miller, Robert A. McIntosh, Southwest Research Institute (United States); Paul Harrison, William P. Walters, Kestrel Corp. (United States)

Differential Excitation Spectroscopy (DES) is a new pump-probe detection technique which characterizes molecules based on a multi-dimensional parameterization of the rovibrational excited state structure, pump and probe interrogation frequencies, as well as the lifetimes of the excited states. Under appropriate conditions, significant modulation of the ground state can result. DES results provide a unique, simple mechanism to validate and understand various molecules in support of relevant science. In addition, the DES multi-dimensional parameterization provides an identification signature that is highly unique and has demonstrated high levels of immunity from interferents, providing significant practical value for high-specificity material identification.

Benzene and various chlorinated solvents have been used as degreasing agents in many industrial and military facilities and have often contaminated groundwater and been dispersed from their original locations by plumes in the groundwater. The vapors from these solvents then show up under previously uncontaminated facilities. A current challenge is to provide continuous monitoring of vapors in potentially contaminated facilities to ensure workplace safety. A DES gas-phase testbed was constructed and ab initio modeling calculations were performed on benzene, dichloroethylene, trichloroethylene, tetrachloroethane, chloroform and carbon tetrachloride; subsequent validation demonstrated the very specific DES responses to be used to provide the signatures needed for continuous monitoring as well as to establish limits of detection for the technique.

9490-26, Session PTue

Sensors for isolation of anti-cancer compounds found within marine invertebrates

Gordon W. Wiegand, Amanda C. LaRue, Medical Univ. of South Carolina (United States)

Highly evolved bacteria living within immobile marine animals are being targeted as a source of antitumor pharmaceuticals. This paper describes 2 electo-optical sensor systems developed for identifying species of tunicates and actinobacteria that live within them. Two stages of identification include 1) a benthic survey apparatus to locate species and 2) a laboratory housed cell analysis platform used to classify their bacterial micro-biome. Marine Optics Sampling- There are over 2000 species of Tunicates that thrive in diverse habitats. We use a system of cameras, GPS and the GPS/photo integration application on a PC laptop to compile a time / location stamp for each image taken during the dive survey. A shape-map of x/y coordinates of photos are stored for later identification and sampling. Bacteria flow cytometry-Low noise circuitry is applied to sensor optics to detect a full range of bacteria extracted from invertebrates and presented to a specialized flow cytometer. A laser beam is focused by cross-cylindrical lenses to form an elliptic spot on the cell / laser intercept. Light scatter is detected at 3 different angles by applying a system of transfer optics and photomultiplier sensors at 1-5°, 35° and 90° from the optical axis. Fluorescence is also measured on a cell- by- cell bases to determine the presence of chlorophyll, accessory pigments and DNA. Pulses originating from these parameters are processes in parallel and displayed in a 3 dimensional cloud. Patterns are established for various bacterial species isolated from mapped invertebrates. Confirmation and enrichment of Actiniobacteria is done by electrostatically sorting for microscopic examination and multispectral analysis.

9490-27, Session PTue

Space medical applications of optical 3D scanning

Jeremy Straub, Univ. of North Dakota (United States); Atif F. Mohammad, The Univ. of North Dakota (United States)

This paper considers the utility of 3D scanning in space. In begins by providing an overview of human-size 3D scanning technologies, including their current (limited) use by medical professionals on Earth and how they support science, art and other focus areas. A low-cost and lightweight optical 3D scanner developed and deployed at the University of North Dakota is presented as a model for how a 3D scanner could be deployed on a spacecraft or the International Space Station to support telemedicine for assessing astronauts' health and for performing scientific experiments (involving astronauts and/or inanimate objects). The types of disorders which could be detected or assessed using a 3D scanner are discussed and the value of the 3D scanner in both preventative medicine and treatment is considered. Mass, volume, power consumption, bandwidth utilization, cost and space utilization are considered in light of the astronaut health benefits and, then, in the context of using the system for astronaut health monitoring, human experiments, non-human experiments and space station (or experiment, etc.) maintenance. The use of the optical 3D scanning technology is compared to other approaches (blue light and laser scanning) in light of these key metrics. Multiple scenarios for scanner use are presented and assessed, including responding to an acute injury and the monitoring of muscles over time during the mission. From this, it is concluded that the 3D scanner would provide comparatively high benefit at low monetary, mass, volume, power and data costs. We also consider how the 3D scanner could be utilized to enable outreach activities via capturing imagery and CAD models of objects in microgravity.

9490-28, Session PTue

Early detection and monitoring of malaria

Mohammed Z. Rahman, LaGuardia Community College (United States); Leonid Roytman, The City College of New York (United States); Abdelhamid Kadik, LaGuardia Community College (United States); Dilara A. Rosy, Univ. of Dhaka (Bangladesh)

Global Earth Observation Systems of Systems (GEOSS) are bringing vital societal benefits to people around the globe. In this research article, we engage undergraduate students in the exciting area of space exploration to improve the health of millions of people globally. The goal of the proposed research is to place students in a learning environment where they will develop their problem solving skills in the context of a world crisis (e.g., malaria). Malaria remains one of the greatest threats to public health, particularly in developing countries. The World Health Organization has estimated that over one million die of Malaria each year, with more than 80% of these found in Sub-Saharan Africa. The mosquitoes transmit malaria. They breed in the areas of shallow surface water that are suitable to the mosquito and parasite development. These environmental factors can be detected with satellite imagery, which provide high spatial and temporal coverage of the earth's surface. We investigate on moisture, thermal and vegetation stress indicators developed from NOAA operational environmental satellite data. Using these indicators and collected epidemiological data, it is possible to produce a forecast system that can predict the risk of malaria for a particular geographical area with up to four months lead time. This valuable lead time information provides an opportunity for decision makers to deploy the necessary preventive measures (spraying, treated net distribution, storing medications and etc) in threatened areas with maximum effectiveness. The main objective of the proposed research is to study the effect of ecology on human health and application of NOAA satellite data for early detection of malaria.

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9491-15, Session 1

Analysis of the coupling optical fiber ultrasonic sensor for partial discharges detection

Fengmei F. Li, Yiying Liu, Linjie Wang, Chen Yu, Xi'an Jiaotong Univ. (China)

Abstract: Reliable operation of power apparatus is required for efficient power system. Insulation failure is one of the major causes of catastrophic failure of power system. It is established that partial discharge (PD) causes insulation degradation and premature failure of insulation. So it is important to detect PDs in electrical equipment. Fiber optic sensors with some unique merits including electromagnetic interference immunity, lightweight and good insulation are getting more and more attention in PDs detection based on acoustic emission technology.

In this paper, a coupling optical fiber ultrasonic sensor with fused-tapered coupling structure which can be used to detect partial discharge phenomenon of high voltage power equipment were theoretically and experimentally analyzed. One input light is divided into two unchanged output parts, while passes through a typical coupling optical fiber ultrasonic sensor with a thin waist and two tapered sections. When an acoustic wave impinges on this sensor, the effective length of coupling zone and the stress distribution is changed according to strain effect. These changes can then cause the variation of the coupling optical power of the sensor in our analysis, the coupling of the 'taper transition' region as well as the 'couple waist' region were both considered, in order to make the coupling principle of the coupling optical fiber sensor more accurate. The finite element method was applied to further analyze the relationships between the strain and the structure parameters of the sensor. The model was established by a series of geometrical equations, which were deduced to describe the realistic coupler structure including the 'degree of fusion', the 'shape of taper', and the 'shape of waist'. The simulation results demonstrate that the structure parameters and stress distribution of the sensor play an important role in the sensing mechanism. Consequently, the performance of the fiber sensor in terms of its frequency response and the sensitivity can be improved by optimizing the structure parameters of the coupling region. Then according to the theoretical analysis, an optical fiber sensor was fabricated and the acoustic emission of PD detection experiment was carried out.

Experiments results show that the bandwidth of the sensor was in the range of 10 kHz up to 2MHz. Therefore, it is obvious that the performance of this fiber optic ultrasonic sensor was significantly superior to other conventional piezoelectric-based sensors in partial discharge detection.

9491-1, Session 2

Harsh environment compatible chemical sensors: plasmonics and electrochemical device principles

Michael A. Carpenter, SUNY College of Nanoscale Science and Engineering (United States)

Metal oxide nanomaterials have served as a foundation for chemical sensor development studies for nearly 20yrs. Recent work has shown that the surface plasmon resonance band of gold nanomaterials embedded in metal oxide heterostructure films is used both as an energy harvesting device structure as well as an optical beacon for the detection of emission gases, CO, NO2 and H2, at temperatures ranging between 500 and 800oC. Challenges for their detection include high levels of sensitivity, the selective detection of the gas of interest within a catalytically active environment as well as surmounting future integration challenges. Recent work will be detailed which shows the implementation of plasmonic based sensing arrays for the detection of emission gases. Coupled with these recent studies is the novel design of plasmonic arrays that are being developed for their energy harvesting capabilities. First of a kind studies will be detailed on these structures that include their energy harvesting characteristics and subsequent detection of emission gases without the need of an external excitation source. Potentiometric oxygen sensors based on yttria-stabilized zirconia are the most extensively used gas sensor in the combustion industry, used for controlling fuel injection in gasoline-powered vehicles and optimizing combustion in coal-fired power plants. Currently, the dimensions of these sensor systems range from 10cm to meters, and need access to air, thus limiting their size and placement. MEMS procedures used for producing millimeter sized potentiometric gas sensors with the necessary technical and cost attributes required for use within combustion applications will be detailed.

9491-2, Session 2

Growth and morphology of lead tin selenide for MWIR detectors

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No Abstract Available

9491-3, Session 2

Atomic layer deposited passivation films for AlGaN/GaN high electron mobility radiation dosimeters

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Atomic layer deposition (ALD) of thin films has gained interest by the semiconductor industry due to their high quality (continuous and pinhole-free) gate dielectric thin films and precise thickness control to the angstrom level. Thus ALD is a candidate approach for creating gate dielectrics with precise thickness, quality control as well as radiation-tolerance. Wide bandgap material platforms are an attractive option for development of total ionizing dose (TID) radiation dosimeters due to their radiation hardness and thermal stability, which is a direct result of their large bandgap (3.4 eV) and high atomic bond energy (8.92 eV/atom). Current radiation dosimeters are limited to operation at room temperature, have limited accuracy and sensitivity. Thus these devices are prone to failure in harsh environments (high temperature, high radiation) and require complex, bulky, and expensive packaging. Thus, gallium nitride (GaN) is an attractive option for developing radiation dosimeters. By utilizing the electrical response of two dimensional electron gas (2DEG) at the AlGaN/GaN interface to ionizing radiation such as gamma radiation, highly sensitive radiation dosimeters can be developed. This paper presents TID sensing devices fabricated with ALD gate dielectric films on AlGaN/GaN HEMT structures exposed to a total ionizing dose levels up to 2 MRad from a Co-60 source without any shielding. The response of the devices is compared with similar devices fabricated without ALD dielectric thin films. Additionally, the current voltage

(I-V) response of the devices will be investigated after using thermal annealing at temperatures up to 200°C to heal the dosimeters.

9491-4, Session 2

Solar cells for harsh environments uses based on InGaN/GaN multiple quantum wells

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Harsh electronics is an emerging field aiming at the promotion of device capability and applicability in harsh environments, including the extremes of pressure, vibration, and chemically corrosive environments. For practical uses, harsh electronic systems are required to be self-powered and operated independently because their working environments are usually inaccessible for human. In general cases, sunlight is one of the most suitable energy sources due to the absence of resources in harsh terrains. However, a harsh environment-sustainable solar cell is still deficient, because most semiconductor photovoltaic (PV) devices suffer serious degradation under high temperatures (volcanos, outer space, planet's orbits and near-sun missions) and long-term radiation exposure (cosmic rays, upper layers of the atmosphere, military and civil nuclear facilities). The performance loss in high-temperature environments is due to the narrowing of bandgap while elevating the temperature, which leads to a severe decrease of open-circuit voltage (Voc) and fill factor (FF), resulting in an overall degradation of efficiency. For example, the efficiencies of crystalline Si and GaAs solar cells are reduced by ~0.45% and ~0.21% for every degree increase at the temperatures higher 40 °C, respectively. In addition, under long-term radiation exposure, the high-energy particles deteriorate the performance of solar cells over time and eventually result in failure/reset. Although off-pointing technology, active cooling techniques, and passivation from radiation are possible approaches, a reliable PV operation in high temperature regimes with high radiation resistance is still demanded.

In this study, we explore InGaN/GaN MQW high-temperature solar cells with superior radiation tolerance promising to harsh-environments/space applications for the first time. Different from conventional solar cells, short-circuit current (Jsc) and FF of MQW solar cells remarkably increase with temperature due to the implementation of GaN-based materials and MQWs, which results in a significant improvement in efficiency at 700 K. Moreover, the PV devices retain the initial performance at room temperature after high-temperature operation without failures or thermal breakdowns. Under high-energy proton irradiation, the devices exhibit a slow degradation compared to conventional solar cells, demonstrating a predicted lifetime of >30 years under solar proton storm. This study paves the way for InGaN/GaN MQW solar cells to harvest energy efficiently under extremely harsh (hot/radiative) environments.

9491-5, Session 2

Irradiation effects of graphene-enhanced gallium nitride (GaN) metal-semiconductor-metal (MSM) ultraviolet photodetectors

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Ultraviolet (UV) photodetectors are used for applications such as flame detection, space navigation, biomedical and environmental monitoring. Oftentimes, the extremes of temperatures, radiation, salinity and/or corrosive chemicals require sensor materials that can withstand such harsh environments and function reliably. For example, a sun sensor uses UV light to assist with determination of spacecraft orientation and may be exposed to both ionizing radiation and extreme temperature swings. Gallium nitride is an ideal device material platform with a wide bandgap (3.4 eV) enabling room temperature operation and visible-blindness, tunable cutoff wavelength selection based on ternary alloy mole fraction, high current density, thermal/chemical stability and radiation hardness due to the strength of the chemical bond. For this study, GaN-based MSM photodetector architecture consists of conductive interdigitated electrodes fabricated on thin film GaN-on-sapphire substrates. The electrodes and semiconductor substrate serve as back-to-back Schottky contacts. While robust, MSM photodetectors are typically subject to topside illumination losses due to the opacity of metal electrodes, which can reduce symmetric device active area by 50 percent. Studies have shown improved MSM photodetector performance using semi-transparent or transparent electrodes. Graphene, with outstanding electrical, optical and mechanical properties and a flat absorption spectrum from 300 to 2,500 nm, has potential use as a transparent conductor for GaN-based MSM photodetectors. The graphene-enhanced MSM UV photodetectors are fabricated with the graphene acting as the metal portion of the device. The MSM UV photodetector properties and behavior are studied after exposure to ionizing radiation using a UV light source under ambient and irradiated conditions (Co-60).

9491-6, Session 2

Investigation of the optical and sensing characteristics of nanoparticle arrays for high temperature applications

Gnanaprakash Dharmalingam, Michael A. Carpenter, SUNY College of Nanoscale Science and Engineering (United States)

Monitoring polluting gases such as CO and NOx emitted from gas turbines in power plants and aircraft is important, in order to both reduce the effects of such gases on the environment as well as to optimize the performance of the respective power system. Fuel cost savings as well as a reduced environmental impact can be realized if air traffic utilized next generation jet turbines with a emission/performance control sensing system. These monitoring systems must be sensitive and selective to gases and reliable and stable under harsh environmental conditions where the operation temperatures are in excess of 500C within a highly reactive environment. In this work, plasmonics based chemical sensors with nanocomposites of a combination of gold nano particles and Yttria Stabilized Zirconia (YSZ) has enabled the sensitive (PPM) and stable detection (100s of hrs) of H2, NO2 and CO at temperatures of 500 C. Selectivity remains a challenging parameter to optimize and a layer by layer sputter deposition approach has been recently demonstrated to modify the resulting sensing properties through a change in the morphology of the deposited films. It is expected that further enhancements would be realized through control of the shape and geometry of the catalytically active Au nanoparticles. This level of control has been realized through the use of electron beam lithography to fabricate nanocomposite arrays. Sensing results towards the detection of H2 will be highlighted with specific concerns related to optimization of these nanorod arrays detailed.

9491-7, Session 2

Wireless photonic power and data transfer to dormant devices

Harbans S. Dhadwal, Jahangir Rastegar, Dake Feng, Philip Kwok, Omnitek Partners, LLC (United States)

Need exists for untethered transmission of electrical power and data to remote devices and sensors, with some imposing additional time and environmental constraints. Several solutions exist, including electromagnetic induction and radiation. Here we focus on the use of photonic power which is an optimized optical to electrical conversion solution, used for both wireless and guided transmission. High photonic conversion efficiencies,

approaching 50% have been demonstrated for wavelength matched laser diodes and photovoltaic cells. Typically, each a 2 mm diameter cell is capable of producing 500 mW of electrical power, under continuous illumination with a 1 W laser diode. For higher output powers, multiple cells can be combined or a single larger area PV cells can be used, both approaches have been commercialized. However, these existing solutions do not meet the needs of rapid, one-time energy transfer to remote devices, such as munition shells prior to launch.

We report on the design and fabrication of a 16 PV cell array that provides power and data transfer to a munition shell, when illuminated by a cluster of laser diodes. The power beam and the PPC cell array are also utilized to establish a communication link, the speed of which is determined by the PPC rise time. Fast energy transfer time is obtained through the use of an optimized illumination profile, together with a switched inductor circuit for charge transfer to a super capacitor.

9491-8, Session 3

Characterization and calibration of Raman based distributed temperature sensing system for 600C operation

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Fiber optic distributed temperature sensing based on Raman scattering of light in optical fibers has become a very attractive solution for distributed temperature sensing (DTS) applications. The Raman scattered signal is independent of strain within the fiber, enabling simple packaging solutions for fiber optic temperature sensors while simultaneously improving accuracy and robustness of temperature measurements due to the lack of strain-induced errors in these measurements. Furthermore, the Raman scattered signal increases in magnitude at higher fiber temperatures, resulting in an improved SNR for high temperature measurements. Most Raman DTS instruments and fiber sensors are designed for operation up to approximately 300˚C.

We will present our work in demonstrating high temperature calibration of a Raman DTS system using both Ge doped and pure silica core multi-mode optical fiber. We will demonstrate the tradeoffs involved in using each type of fiber for high temperature measurements. In addition, we will describe the challenges of measuring large temperature ranges (0 – 600˚C) with a single DTS interrogator and will demonstrate the need to customize the interrogator electronics and detector response in order to achieve reliable and repeatable high temperature measurements across a wide temperature range.

9491-9, Session 3

Coherent probe-pump-based Brillouin sensor for harsh environments

L. F. Zou, OZ Optics Ltd. (Canada)

A coherent probe-pump-based Brillouin sensor with less than 1mW cw pump power by controlling depletion of the pump beam resulting from the strong coherent interaction of the pump and the probe has been developed. The sensor has been used for some harsh environments, such as leakage detection of oil and gas pipeline, monitoring of thunderstorms and rime ice on electricity power line, and monitoring of nuclear waste repository. The small leakage with the injection pressure of 22 psi and the temperature difference of 22°F between the line temperature and the soil temperature has been detected in five minutes after a leakage happened through 1/8" orifice and the temperature change caused by the leakage increased with time during 15 minutes leakage operating. The use of these results to monitor pipeline leakage and to avoid false alarm in real application is discussed. The effects of thunderstorms and rime ice on the power line produced by freezing rain have been identified by monitoring strain on an OPGW with 140km optical fiber. Variation of strain between day and night on the OPGW cable can be exploited, used to accurately model the environmental heating and cooling of the OPGW, and pro-rated for the conductor under earth. The fiber types at high gamma doses that represent the harsh environment constraints associated with the considered application have been investigated by the coherent probe-pump-based Brillouin sensor. The dose dependence of the radiation-induced attenuation (RIA) of optical fibers in the 1 to 10 MGy dose range shows that the responses strongly depend on the fiber composition.

9491-10, Session 3

Potential of commercial single-mode optical fibers as distributed sensors for high temperature measurement with PPP-BOTDA

Yi Bao, Yizheng Chen, Fujian Tang, Weina Meng, Genda Chen, Missouri Univ. of Science and Technology (United States)

Cost effective ways of measuring high temperatures and temperature distributions in large-scale energy production and infrastructure systems are quite desirable in civil, defense, oil and gas applications. In this study, a single-mode optical fiber is used as a distributed sensor to measure temperatures up to 1000ºC. The optical fiber was protected by a heat resistant glass tube with inside and outside diameters of 4 mm and 8 mm, respectively. The glass tube was monotonously heated at a thermal gradient of 8°C/min until 1000°C, and then was monotonously cooled to room temperature (22°C) in a thermostatic chamber. The distribution of Brillouin frequency shifts along each fiber were measured by a commercially available Neubrescope (Model NBX-7020) at different temperatures with pulse pre-pump Brillouin optical time domain analysis (PPP-BOTDA). A parabolic regression equation was developed to characterize the nonlinear thermo-optic effect through the change of Brillouin frequency. The accuracy of temperature measurement is ±2°C. The coefficients in the parabolic equation have been determined experimentally. The measurement repeatability and spatial resolution are ±1°C and 4 cm, respectively. The optical fiber sensor is stable at 800°C for 4 hours. Further works will be directed to investigate measurement potentials and structural behaviors up to 1000 °C for 4 hours.

9491-11, Session 4

Optical sensors for harsh environment applications

Rachit Sharma, GE Global Research (India); Sandip Maity, GE Global Research (India) and GE India Technology Centre Pvt Ltd (India); Anish Bekal, Sameer Vartak, Arun K. Sridharan, Chayan Mitra, GE India Technology Centre Pvt. Ltd. (India)

In this past decade, industrial sectors of power generation and oil & gas, have seen a steady increase in the demand for lower costs, fuel savings, better efficiency, and longer asset life. As a result, higher reliability, optimized performance, and advanced analytics will be the key drivers in these sectors in the coming decade. Intelligent machines with fast & reliable online sensing and controls, in combination with advanced analytics, are leading to a profound transformation of the global industrial sector. Many a times, true performance enhancement requires measurement of machine parameters in harsh environments (high pressures or temperatures or both). Therefore, to support the development of advanced analytics and to augment the industrial assets with digital intelligence, harsh environment sensors are going to be increasingly important in the times to come.

Optical sensors are highly promising for harsh environment applications because they offer some key advantages over conventional techniques, such as their speed of response, in-situ capability, ease of deployment, and their repeatability/reliability. In addition, by using lasers, one can effectively remove the error contribution due to the measurement system interaction with the process, hence enabling high specificity and selectivity. Some major parameters which are often used for monitoring and control applications in industrial assets are temperature, pressure, species concentrations, and flows. Laser based techniques, as demonstrated in literature [1], can be used to measure all of these parameters over a variety of temperature and pressure ranges inaccessible by conventional sensors. Sensor systems based on tunable diode laser absorption spectroscopy, particle imaging velocimetry, laser-induced fluorescence techniques are capable of providing in-situ measurement of temperature, pressure, and flow with fast response time [2-4]. Infra-red camera and SiC based optical emission sensors provide monitoring of process dynamics [5]. A desired harsh environment application of optical sensing is gas analysis. In this paper, the authors present systems based on tunable diode laser absorption spectroscopy as effective and reliable tools to carry our real-time, highly selective, in-situ trace gas analysis. The authors present the measurement capabilities and implementation challenges of these systems towards serving as possible solutions to key industrial problems.

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9491-12, Session 4

Analysis of the acoustic response in water and sand of different fiber optic sensing cables

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Distributed Acoustic Sensing (DAS) is a highly promising technology to efficiently monitor assets for energy production and transportation, both off- and on-shore, such as boreholes, pipelines and risers.

The aim of the hereby-presented measurements is to evaluate the sensitivity of the different optical fiber cables to acoustic signals in sand and water, independently from the DAS read-out unit type and manufacturer. Acoustic sensing cables specifically designed by BRUGG Cables are characterized and compared to standard telecommunication cables. The spectral response of each cable was quantified using an all-fiber Mach-Zehnder Interferometer. The response was also measured with calibrated microphones in order to convert the measurements into absolute physical units (Pascal). The measurement campaign is part of an investigation program for a reliable DAS system, which comprises the sensing cable (including installation procedure), the interrogator unit and suitable software.

9491-13, Session 4

Optical fiber distributed temperature and distributed acoustic sensing for remote and harsh environments

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Advances in opto-electronics and associated signal processing have enabled the development of optical fibre distributed acoustic and temperature sensors. Unlike systems relying on discrete optical sensors a distributed system does not rely upon manufactured sensors but utilises passive custom optical fibre cables resistant to harsh environments, including high temperature applications.

The principle of distributed sensing is well known from the Distributed Temperature Sensor (DTS) which uses the interaction of the source light with thermal vibrations (Raman scattering) to determine the temperature at all points along the fibre. Distributed Acoustic Sensing (DAS) uses a novel digital optical detection technique to precisely capture the true full acoustic field (amplitude, frequency and phase over a wide dynamic range) at every point simultaneously. A number of signal processing techniques have been developed to process a large array of acoustic signals to quantify the coherent temporal and spatial characteristics of the acoustic waves.

Predominantly these systems have been developed for the oil and gas industry to assist reservoir engineers in optimising the well lifetime. Nowadays these systems find a wide variety of applications as integrity monitoring tools in process vessels, storage tanks and piping systems offering the operator tools to schedule maintenance programs and maximize service life. Results from field deployments will be presented.

9491-14, Session 4

Planetary atmospheres minor species sensor balloon flight test to near space

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The Planetary Atmospheres Minor Species Sensor (PAMSS) is an intracavity laser absorption spectrometer that uses a mid-infrared quantum cascade laser in an open external cavity for sensing ultra-trace gases and vapors. The system consists of optical and electronics subsystems for a combined weight under 10 kg including batteries. The laser operates at 8.1 micron wavelength in the molecular fingerprint region of the spectrum and had been calibrated to have parts-per-billion sensitivity. An environmental test chamber enabled pre-flight laboratory testing in near-space conditions of temperatures below -60 C and pressures below 10 mbar. PAMSS was integrated into a balloon gondola operated by Near Space Corporation (Tillamook OR) and achieved flight objectives by maintaining an altitude higher than 27.4 km for at least 10 minutes on 17 July 2014. Successes included continuous operation and survival of software, electronics, optics, laser, and optical alignment during the extreme conditions of flight and a hard landing. Operation of PAMSS in the relevant environment of near space has elevated the Technical Readiness Level to 6. These results demonstrate the potential of PAMSS as a future local trace-gas sensor for operation in harsh environments in the search for life and resources on planetary bodies. Promise is also indicated for atmospheric science on such bodies, including Earth, and including questions of global warming and pollution. PAMSS may find additional application in local calibration and validation of results from orbit-based remote sensing instruments.

9491-16, Session 4

Optical fiber reliability in subsea monitoring

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Fiber optic cables have been successfully deployed in ocean floors for decades to enable trans-ocean telecommunication. The impact of strain and moisture on optical fibers has been thoroughly studied in the past 30 years. Cable designs have been developed to minimize strain on the fibers and prevent water uptake. As a result, the failure rates of optical fibers in subsea telecommunication cables due to moisture and strain are negligible. However, the relatively recent use of fiber optic cables to monitor temperature, acoustics, and especially strain on subsea equipment adds new reliability challenges that need to be mitigated. This paper will provide a brief overview of the design for reliability considerations of fiber optic cables for subsea monitoring. In particular, experimental results on fibers immersed in water under varying accelerated conditions of static stress and temperature will be discussed. Based on the data, an assessment of the survivability of optical fibers in the subsea monitoring environment will be presented.

9491-17, Session PThu

Thermal stability and energy harvesting characteristics of Au nanorods: harsh environment chemical sensing

Nicholas A. Karker, Gnanaprakash Dharmalingam, Michael A. Carpenter, SUNY College of Nanoscale Science and Engineering (United States)

Monitoring the levels of polluting gases such as CO and NOx from high temperature (~ 500°C) combustion environments requires materials with high thermal stability and resilience that can withstand harsh oxidizing and reducing environments. Au nanorods (AuNRs) have shown potential in plasmonic gas sensing due to their catalytic activity, high oxidation stability, and absorbance sensitivity to changes in the surrounding environment. By using electron beam lithography, AuNR geometries can be patterned with tight control of the rod dimensions and spacings, allowing tunability of their optical properties. Methods such as NR encapsulation within an yttria-stabilized zirconia overcoat layer with subsequent annealing procedures will be shown to improve temperature stability within a simulated harsh environment.

Since light sources and spectrometers are typically required to obtain optical measurements, integration is a major barrier for harsh environment sensing. Plasmonic sensing results will be presented where thermal energy is harvested by the AuNRs which replaces the need for an external incident light source. Results from gas sensing experiments that utilize thermal energy harvesting are in good agreement with experiments which use an external incident light source. Principal Component Analysis results demonstrate that by selecting the most “active” wavelengths in a plasmonic band, the wavelength space can be reduced from hundreds of monitored wavelengths to just four, without loss of information about selectivity of the AuNRs. By combining thermal stability, the thermal energy harvesting capability, and the selectivity in gas detection (achieved through multivariate analysis), integration of plasmonic sensors into combustion environments will be greatly simplified.

9491-18, Session PThu

Microfabricated electrochemical sensors for combustion applications

Vitor A. Vulcano Rossi, SUNY College of Nanoscale Science and Engineering (United States); Max Mullen, The Ohio State Univ. (United States); Nicholas A. Karker, Zhouying Zhao, SUNY College of Nanoscale Science and Engineering (United States); Marek Kowarz, Smart System Technology & Commercialization Ctr. (United States); Prabir K. Dutta, The Ohio State Univ. (United States); Michael A. Carpenter, SUNY College of Nanoscale Science and Engineering (United States)

Oxygen sensors are extensively used throughout the combustion industry. Durability and high cost of current industry standards limit the efficiency and applications of these current sensors. Innovations in electrochemical sensor design will enable the translation of bulk ceramic manufacturing methods into novel semiconductor industry-based microfabrication techniques for the development of cost effective oxygen sensors for combustion applications. Potentiometric oxygen sensors are currently the most extensively used gas sensor in the combustion industry, used for controlling fuel injection in gasoline-powered vehicles (cost of sensors ~ $100) and optimizing combustion in coal-fired power plants (cost of sensor ~ $5000). Currently, the dimensions of these sensor systems range from ten centimeters to meters, and need access to air, thus limiting their size and placement. With the commercial oxygen sensor design, advantages of miniaturization will only be realized if the need for an external air reference is eliminated. The recent discovery of an oxygen sensor by Argonne and Ohio State with a self-contained reference gas system, fabricated by a unique deformation bonding method and having unsurpassed oxygen-sensing capabilities, provides a unique opportunity to adapt MEMS-based fabrication technology to the design of chemical gas sensors. Application of MEMS procedures for producing millimeter sized potentiometric gas sensors with the necessary technical and cost attributes required for widespread use within combustion applications will be described. Specifically these include a summary of the deposition, processing and bonding methods used. Design attributes of the electrochemical sensor as well as characterization of device materials and operation characteristics will be detailed.

9491-19, Session PThu

Data communication through multiple physical media: applications to munitions

Harbans S. Dhadwal, Jahangir Rastegar, Dake Feng, Philip Kwok, Omnitek Partners, LLC (United States)

Electronic systems comprising of sub-assemblies, distributed across different physical media, require seamless communication between processors and sensors embedded in the disparate volumes. For example, smart munitions systems embed sensors and other key control electronics, throughout the structure, in vastly different physical media. In addition to the obvious space constraints, these structures are subjected to high G forces during launch. Thus, communications through wire harnesses become cumbersome, make assembly process and testing difficult, and challenging to make survive high G firing.

Here we focus on an approach that takes advantage of the optical transparency of epoxy material commonly used in potting electronic components in munition shells, as well as the wave guiding that is possible through the body of the shell which is made from composite materials. Experimental results show that a wireless optical link, connecting various parts of the distributed system, is possible at near IR frequencies. Data can be rapidly parsed between a processor, sensors and actuators. We present theoretical rationale and experimental results for a commercial epoxy system, which was used to embed a number of IrDA devices inside the cone of 120 mm mortar shell. The IrDA devices were used to establish an ad hoc network, linking and sharing data, between various sensors and a central processor, within the confines of a small potted space. The data rate is determined by the various IrDA standards, for example, VFIR calls for a 16 Mbps link. New Giga-IR standards are being developed for future devices. IrDA devices have been used for convenience but any wavelength near the IR band can be utilized

9491-20, Session PThu

Lessons learned and experience from land collapse accidents using remote sensing and GIS: case study of continuous land collapse in east Cairo area, Egypt

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Early warning and Late or no response was the tradition behavior of the local authority in Egypt for the last decades. In the area East of Cairo where a huge body of slum community named Manshiyyat Naser and El Deweiqa was studied for land collapse geo- hazard. Different environmental factors have their impacts on the deterioration of the physical environment parameters. These parameters can be classified into manmade and natural ones. The man made include heavy trucks movement, misuse of water in garden irrigation, extreme use of explosives in mining activity nearby the area, and overall the uncontrolled sewage system. The physical parameters include country rock type as hard fractured limestone, shale, etc. as these different types of rocks have different hardness and durability and resistivity to physical weathering and erosion. Stratigraphy parameter as the layers has different hardness and sometimes hard rocks are overlying soft detrital sediments. Faults and cracks have a magnificent impact as structure density affect the durability of such rocks. Different geochemical characteristics of the rocks like clay minerals that have swelling mechanism or dissolving salts plays an important role in the deterioration of these rocks. Presence of scarps and steep slopes is one of these factors. This research is concerned with assessment of one of the land collapse accidents that occurred and lessons learned from that case to overcome the bad impact of the absence of monitoring and documentation of recent expected ones. Multi-temporal multi-sensors imageries were used to monitor the scarp and areas for fractures developments and change of rock properties due to sewage water seepage and dumping different types of trashes. Scarp area that was subjected to collapse was outlined and a database for it was constructed before collapse happened. Another image of the same area after collapse was used also to make the necessary comparisons regarding damage identification. An inventory for the number of buildings that was damaged due to land collapse was done. Using multi-temporal satellite images was the only way to assess the damage in area and number of buildings due to lack of any type of information or maps for such slum area.

The research was concluded to the decision makers to develop a monitoring mechanism using remotely sensed data and establishment of a database for the area including cadastral maps. Another important recommendation was to open a corridor way for emergency and rescue purposes as the area lacks such way for emergency, rescue and accessibility.

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9492-1, Session 1

Cutting the cord: toward wireless optical intensity interferometry *(Invited Paper)*

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Intensity interferometry, which was first used for obtaining ultra--high-resolution image information in astronomy in the 1960's and 1970's, is now being revived using modern detectors and electronics. This paper explores the possibility of wireless optical interferometry made possible by technological advancements in timing correlation, signal processing, and detector technology. The most important of these advances is the development of single-photon avalanche diode (SPAD) arrays. These in theory will allow for each station of a long-baseline optical intensity interferometer to simultaneously conduct a number of independent correlation measurements at slightly different wavelengths, with each wavelength hitting one pixel of the array. This mitigates the well-known problem of low signal-to-noise in intensity interferometers. In addition, the much higher timing resolution of modern electronics over what was available in the 1970's also greatly increases the signal-to-noise ratio. The first part of this paper will discuss the projected performance limits for an interferometer based on these ideas.

Intensity interferometry relies only on obtaining precise photon arrival times, so that photon correlations can be found and studied after the fact with signal processing techniques. In the second part of the paper, we explore the implications of this fact, namely, that the data collection at each station is in effect an independent operation. If the stations can be approximately synchronized over minutes or tens of minutes, then there is no need for central data collection with a single timing unit; the array can be wireless. The possibilities for this type of operation and plans to attempt it at Southern Connecticut State University will be discussed. If this can be achieved, then baselines of at least one to several kilometers may be possible in optical interferometry in the coming years, which would improve the resolution over the current generation of amplitude-based optical interferometers by a factor of at least 10.

9492-2, Session 1

Time and spectrum-resolving multiphoton correlator for 300-900 nm

Piotr L. Kolenderski, Nicolaus Copernicus Univ. (Poland); Kelsey Johnsen, Institute for Quantum Computing (Canada); Thomas D. Jennewein, Univ. of Waterloo (Canada); Marilyne Thibault, Institute for Quantum Computing (Canada); Alberto Tosi, Carmelo Scarcella, Politecnico di Milano (Italy)

We demonstrate a single-photon sensitive spectrometer in the visible range, which allows us to perform time-resolved and multi-photon spectral correlation measurements at room temperature. It is based on a monochromator composed of two gratings, collimation optics and an array of single photon avalanche diodes. The time resolution can reach 110 ps and the spectral resolution is 2 nm/pixel, limited by the design of the monochromator. This technique can easily be combined with commercial monochromators, and can be useful for joint spectrum measurements of two photons emitted in the process of parametric down conversion, as well as time-resolved spectrum measurements in optical coherence tomography or medical physics applications.

9492-3, Session 1

Photon counting camera for fluorescence lifetime imaging *(Invited Paper)*

Werner Zuschratter, Yury Prokazov, Evgeny Turbin, André Weber, Leibniz Institute für Neurobiologie Magdeburg (Germany); Roland Hartig, Otto-von-Guericke Univ. Magdeburg (Germany)

Conventionally, fluorescence lifetime imaging microscopy (FLIM) acquisition by single photon counting (SPC) method employs point detectors in combination with scanning. Here we present a detection system for wide-field FLIM acquisition. In contrast to frequency domain and time-gating wide-field approaches the system enables a pure photon-counting mode providing all the advantages of the SPC method for wide-field microscopy. This is achieved by registration of the position together with temporal information for every incident photon eliminating the need of an imaging scanner.

The light detecting unit of the system consists of a micro-channel plate based photomultiplier tube (MCP-PMT) that combines high positional resolution with ultra-fast reaction time. For the positional readout a capacity coupled imaging technique (charge image) has been employed in combination with a charge division anode. Using an artificial neural networks computation model the method allows to reconstruct the position of the incident photon as precise as 20 microns over the detector active area of 25 mm diameter. Thus, the resulting image quality equals roughly the resolution of a megapixel conventional CCD camera. Importantly, to reach such a resolution only 9 charge acquisition channels out of 14 interconnected readout electrodes were necessary. The temporal resolution, provided by the detector, undercuts 50 ps. The detecting unit together with the supporting electronics and cooling is packed in a nearly cubic lightweight housing of just 1-liter volume. Connected to a regular fluorescence wide-field microscope the camera system permits reliable FLIM acquisition by accurate single photon counting but also allows time correlated imaging applications in other fields.

9492-4, Session 1

48-confocal-spots single-molecule measurements using a custom 48-pixel SPAD arrays with integrated timestamping

Antonino Ingargiola, Univ. of California, Los Angeles (United States); Luca Miari, Ivan Rech, Angelo Gulinatti, Massimo Ghioni, Politecnico di Milano (Italy); Shimon Weiss, Xavier Michalet, Univ. of California, Los Angeles (United States)

In the last 15 years single-molecule spectroscopy has emerged as one of the fundamental tools in biology and biophysics to investigate processes on the single-molecule level. Single-molecule FRET measurements on freely-diffusing molecules, for example, allows to probe the distance between two fluorescent labels in the 3-10nm range. Although powerful, the main limitation of these techniques is the long acquisition times required to acquire a sufficient number of single-molecule events in order to sample the landscape of sub-populations and extract physical parameters. This issue limits the application of these techniques to steady state or quasi-steady-state conditions. High-throughput single-molecule spectroscopy techniques try to overcome this limitation through parallelization of the measurement by multiplexing the excitation sites and the fluorescence detection.

In this work we present the first parallel single-molecule measurement

performed on freely diffusing molecules with 48 excitation spots. The 48-spot excitation pattern is generated from a single laser source employing a Liquid-Cristal-On-Silicon Spatial Light Modulator (LCOS-SLM) and projected into the sample through a high-NA objective lens. The fluorescence of single molecules diffusing through the excitation spots is detected by a novel 48-pixels SPAD array with integrated photon timestamping (implemented in an internal FPGA) and a USB-2.0 interface used to download the data. The plug-and-play USB-2.0 interface allows downloading timestamps to a host PC with mean count rates up to 70 kHz per channel, more than enough for single-molecule measurements. Thanks to the integrated time-stamping function and the USB interface the need for external expensive acquisition hardware is avoided.

In single-molecule measurements the maximum excitation intensity must lie in a narrowly defined range in order to avoid the fluorophore saturation (at high intensities), yet achieving single-molecule detection. Therefore a fundamental challenge we faced was generating a sufficiently uniform 48-spot pattern so that all the spots would lie in this suitable range of excitation intensities.

Regarding the emission path, the two main experimental challenges which needed to be solved were detector alignment and demonstration that the lower photon detection efficiency (PDE) of the detector in the red region of the spectrum (compared to the highest-PDE "thick" SPADs only available as single-SPAD units), did not impede these measurements. Here we will show that all these issues can be satisfactorily solved, resulting in single diffusing molecules bursts which are clearly resolved in all the 48-spots.

In conclusion, this works demonstrate a fully functional single-molecule measurements system achieving a 48-fold increase in speed, opening the way to high-throughput single-molecule FRET analysis among many other potential applications.

9492-5, Session 2

Single photon detectors and quantum sensing *(Keynote Presentation)*

John G. Rarity, Univ. of Bristol (United Kingdom)

This talk will review the development of semiconductor photon counting detector technologies and highlight their role in the emergence and ongoing evolution of quantum sensing, communications and computation. In the mid 1980's it was discovered that low noise silicon avalanche diodes could be used as high efficiency photon counting detectors in 'Gieger mode'. Various groups were studying the fundamental quantum nature of light and the emergence of good detectors allowed the shift from study of fundamentals to the development of applications including single photon range finding and quantum secured key distribution. Development of longer wavelength detectors was then 'pulled' by the need for photon counting at fibre communications relevant wavelengths leading to the development of Germanium and InGaAs devices. Most photon counting detectors have emerged simply by adapting the external electronics around devices developed for linear operation. As the market for photon counting devices has grown various photon counting specific designs have emerged targeting low timing jitter (Si devices), free running operation (InGaAs) and photon counting detector arrays. In this presentation we will give examples of recent work exploiting photon counting detectors in quantum information applications [1] and free running InGaAs detectors in long range DIAL measurement of CO2 concentration [2].

1. B.A. Bell, JGR et al, Multi-Colour Quantum Metrology with Entangled Photons, Phys. Rev. Letts. 111, 093603 (2013)

2. X. Ai, JGR et al, A feasibility study on pseudo-random single photon counting for space-borne atmospheric sensing lidar applications, IEEE Aerospace Conference, 2014

9492-6, Session 3

Quantum key distribution on lit fibre *(Invited Paper)*

Zhiliang L. Yuan, Toshiba Research Europe Ltd. (United Kingdom)

We report recent advances in high bit rate quantum key distribution (QKD) to operate lit telecom networks. We have developed compact, gigahertz-clocked gated single photon detectors based on InGaAs avalanche photodiodes, which naturally act as a temporal filter to reject the Raman nose in lit fibre. With bidirectional 10Gb/s classical data traffic multiplexed in a single fibre using dense wavelength division multiplexing (DWDM), we obtain record secure QKD key rates of 2.38 Mbps and fiber distances up to 70 km. The robustness of the QKD system is further demonstrated over with data lasers launching conventional 0dBm power. Finally, we demonstrated the first field-trial of a quantum-secured DWDM transmission system, in which QKD is combined with 4 ? 10 Gb/s encrypted data and transmitted simultaneously over 26 km of field installed fiber. We discuss the fundamental limit for the QKD performance in the multiplexing environment.

References:

[1] K. A. Patel et al., "Coexistence of high-bit-rate quantum key distribution and data on optical fiber," Phys. Rev. X 2, 041010 (2012).

[2] K. A. Patel et al., "Quantum key distribution for 10Gb/s dense wavelength division multiplexing networks," Appl. Phys. Lett. 104, 051123 (2014).

[3] I. Choi et al., "Field trial of a quantum secured 10 Gb/s DWDM transmission system over a single installed fiber," Opt. Express 22, 23121 (2014).

9492-7, Session 3

Photon-counting communications receiver in the lunar lasercom ground terminal *(Invited Paper)*

Matthew E. Grein, Eric A. Dauler, Andrew J. Kerman, Mark L. Stevens, Richard J. Molnar, Bryan S. Robinson, Daniel V. Murphy, Don M. Boroson, MIT Lincoln Lab. (United States)

No Abstract Available

9492-8, Session 3

Single photon counting for space based quantum experiments

Rakhitha Chandrasekara, Zhongkan Tang, Yue Chuan Tan, Yong Sean Yau, Cliff Cheng, Ctr. for Quantum Technologies (Singapore); Christoph F. Wildfeuer, Kantonsschule Sursee (Switzerland); Alexander Ling, National Univ. of Singapore (Singapore)

Modern long distance quantum entanglement studies are limited to sub-continental distances, recorded up to 150km in free space. Operating an entangled photon source in Low Earth Orbit (LEO) will allow us to study micro gravity effects on entanglement and expand quantum communication applications to intercontinental distances.

We are developing a polarization-entangled photon pair source to be hosted in Cubesat platforms, which we call Small Photon Entangling Quantum System (SPEQS). The SPEQS devices are equipped with Avalanche Photo Diodes (APDs) to monitor the photon pair source in the Cubesat platforms. In a lab environment, typical single photon counting experiment uses cooled (-200C) APDs due to lower dark count rates. But the limited power budget rules out APD cooling in Cubesat platforms. Thus in a typical Cubesat polar orbit, APDs experience varying temperature profile. The APD breakdown

voltage is temperature dependent and affects detection efficiency.

In the SPEQS, APDs are designed to operate in Geiger mode. We use a modified passive quenching; current mode sensing circuit to capture the single photons. There the passive quenched avalanche pulse is split in to two amplitude proportionate signals (top and bottom signals) by using two series sense resistors. These two avalanche signals are detected by a comparator at different voltage references and convert them to CMOS pulses.

The top signal reference voltage is chosen such that it passes all the signals at any operating temperature. Then the bottom signal reference is chosen to maintain the top signal at a fixed amplitude by maintaining a predefined bottom to top count ratio. A change in temperature affects the breakdown voltage of the APD and the top pulse height. The feedback system traces the change of APD top pulse height through the change of bottom to top counter ratio. It adjusts the bias voltage such that the bottom to top count ratio is fixed within a given window (window comparator). This ensures the excess voltage of the APD at a fixed value irrespective of the temperature hence constant detection efficiency.

The robustness of the photon counting system was tested in near space conditions with a correlated photon source in a weather balloon, which reached 35.5km altitude. During the journey the SPEQS device experienced temperature changes ~0.4 0C/min, which can be experienced in a typical LEO orbit.

The APD system was able to capture the correlated photons in all these temperature conditions (ranging from 17 – 30 0C) with out dropping the count rate, which proves robustness of the system. Also it is interesting to check the performance of the window comparator when the temperature is fluctuating and the incident photon count is also changing during the experiment. Another important feature of the window comparator is its enhanced linearity, which extends the saturation point of an APD. This allows prolonged APD operation in space radiation environment.

Currently we are working towards combining active quenching with the window comparator to achieve high counting rates. We will present the SPEQS photon-counting system design, performance and robustness in near space conditions.

9492-9, Session 4

Real-time infrared single-photon imaging with a superconducting nanowire camera *(Invited Paper)*

Martin J. Stevens, Michael S. Allman, Varun B. Verma, Robert D. Horansky, National Institute of Standards and Technology (United States); Francesco Marsili, Matthew D. Shaw, Andrew D. Beyer, Jet Propulsion Lab. (United States); Richard P. Mirin, Sae Woo Nam, National Institute of Standards and Technology (United States)

We have demonstrated a superconducting nanowire camera consisting of 64 individual SNSPD (superconducting nanowire single-photon detector) pixels. Each pixel has an active area of 17 μm x 20 μm, and the 8 x 8 array of pixels are spaced a 40 μm pitch for a fill factor of ~0.25. The camera is biased and read out using a novel row-column readout scheme. Each of the 8 rows is individually biased, and each row and column is individually read out with a chain of room-temperature amplifiers. Output pulses from these amplifier chains are fed into a 16-channel time-tagging unit and to real-time histogramming and coincidence software. Simultaneous voltage pulses on row i and column j indicate that pixel (i,j) has detected a photon.

To test the device, light from a 1550 nm laser is free-space coupled through optical windows to the camera, which is held at a temperature of 800 mK in a closed-cycle cryostat. Because WSi SNSPDs are sensitive to blackbody photons from room temperature, we use two cold bandpass filters inside the cryostat to block most of this background. A computer-controllable image is encoded onto the laser beam with a digital micromirror device, and read out with the superconducting nanowire camera. We have shown that every one of the 64 pixels is sensitive to light, and that the coincidence software can sustain real-time, video-rate imaging with several thousand detected photons per second on each pixel.

9492-10, Session 4

Single photon imaging with superconducting nanowire single photon detectors *(Invited Paper)*

Robert H. Hadfield, Univ. of Glasgow (United Kingdom)

Single nanowire single photon detectors offer single photon sensitivity with free running operation, low timing jitter and low dark counts at infrared wavelengths [1]. Using attenuated laser pulses 1550 nm wavelength, we have employed these devices successfully in time of flight ranging [2] and depth imaging studies in daylight at a range of several kilometres [3]. We are now working to extend this technique to 'ghost imaging' using a source of correlated photon pairs [4]. One photon from the pair at 1550 nm will interrogate an object and be detected via the SNSPD. The second correlated twin (400 nm) will be imaged on a high efficiency CCD. This will allow an image to be rapidly acquired from a large number of modes (>500).

[1] CM Natarajan, MG Tanner, RH Hadfield Superconducting nanowire single-photon detectors: physics and applications Superconductor Science and Technology 25 063001 (2012

[2] RE Warburton, A McCarthy, A Walker, S Hernandez-Marin, RH Hadfield, S Nam, GS Buller Subcentimeter depth resolution using a photon-counting time-of-flight laser ranging system Optics Letters 32 (15) 2266 (2007)

[3] A McCarthy, N Krichel, X Ren, NR Gemmell, MG Tanner, SN Dorenbos, V Zwiller, RH Hadfield, GS Buller Kilometer range time-of-flight depth imaging at 1560 nm wavelength with a superconducting nanowire single-photon detector Optics Express 21 7 8904 (2013)

[4] R Aspden et al EPR based ghost imaging using a single-photon sensitive camera New J Physics 15 073032 (2013)

9492-11, Session 4

High performance superconducting nanowire single photon detectors embedded in silicon nanobeam cavities *(Invited Paper)*

Mohsen K. Akhlaghi, Ellen Schelew, Jeff F. Young, The Univ. of British Columbia (Canada)

We report on the development of ultra-compact superconducting nanowire single photon detectors in a silicon-on-insulator platform for applications in integrated quantum photonics. At the core of these detectors is a very short (8.5um total length) and narrow (8nmx35nm) U-shaped NbTiN superconducting nanowire placed on top of a silicon waveguide (190nmx500nm cross-section). Rather than extending the weakly absorbing nanowire over hundreds of microns to absorb all of the guided light in the silicon, we embed it in an asymmetric 1D photonic crystal microcavity formed by etching a set of carefully designed holes in the waveguide, on either side the nanowire segment. The resulting optical structure is a coherent perfect absorber that uses a minimal volume of superconductor to efficiently and quickly convert incident photons in the waveguide to low-noise electrical pulses. We demonstrate the capacity of this design to achieve close to ideal detection of photons: at 2.05K, the fabricated detectors show ~96+-12% on-chip quantum efficiency for ~1550nm photons with less than a 0.1Hz intrinsic dark count rate. Estimated timing jitter is ~53ps full-width at half-maximum and the reset time is <7ns, both currently limited by read-out electronics. We will discuss the potential impact and application of this detector performance and architecture on various fields.

9492-12, Session 4

Waveguide-integrated WSi-based superconducting nanowire single-photon detectors *(Invited Paper)*

Ryan M. Briggs, Matthew D. Shaw, Francesco Marsili, Andrew D. Beyer, Jet Propulsion Lab. (United States); Justin D. Cohen, Sean Meenehan, Oskar J. Painter, California Institute of Technology (United States)

Superconducting nanowire single-photon detectors (SNSPDs) fabricated from amorphous WSi have been previously demonstrated with high detection efficiency (>90%) and intrinsic broadband response from visible to mid-infrared wavelengths. However, for wavelength-division multiplexing and other applications requiring spectral resolution, SNSPDs must be coupled with external filtering components. We have demonstrated WSi-based SNSPDs integrated with fiber-coupled SiN photonic waveguides, which provide a robust and scalable platform for fabricating arrays of detectors with on-chip filters. As an initial demonstration, waveguide ring resonators were implemented as narrowband filters at telecommunication wavelengths near 1550 nm.

Waveguide-integrated SNSPDs were fabricated using wafer-scale processing on a low-stress SiN on SiO2 photonics platform. Self-aligning, cryo-compatible fiber couplers were formed by etching v-grooves into the Si substrate beneath the photonics layers with suspended SiN inverse-taper waveguide transitions. Nanowire absorbers were patterned on top of single-mode waveguides designed for operation between 1500 and 1600 nm, enabling strong evanescent coupling with the guided waveguide mode and minimal loss from reflections. For spectral filtering experiments, devices were fabricated with in-line high-quality factor (Q ~ 100,000) waveguide ring resonators.

Devices were characterized in a closed-cycle He-3 cryostat operating at 0.5 K. Single-photon detection was observed with count rates in excess of 1 MHz and saturated internal efficiency versus current bias, indicating near-optimal coupling between the waveguides and nanowire detectors. By varying the input wavelength, detectors with in-line ring resonator filters were shown to have a typical on-resonance passband of <100 pm with the expected free-spectral range corresponding to the ring geometry. Typical total system detection efficiency of ~1% was measured, limited primarily by the fiber-to-chip couplers.

9492-13, Session 4

Large-area NbN superconducting nanowire avalanche photon detectors with saturated detection efficiency

Ryan P. Murphy, Matthew E. Grein, Theodore J. Gudmundsen, MIT Lincoln Lab. (United States); Adam McCaughan, Faraz Najafi, Karl K Berggren, Massachusetts Institute of Technology (United States); Francesco Marsili, Jet Propulsion Lab. (United States); Eric A. Dauler, MIT Lincoln Lab. (United States)

Superconducting circuits with SNSPD devices placed in parallel—superconducting nanowire avalanche photodetectors, or SNAPs—have previously been demonstrated to improve the output SNR by increasing the critical current. In this work, we employ a 2-SNAP superconducting circuit with narrow (40 nm) NbN nanowires to improve the system detection efficiency to NIR photons while maintaining high SNR. Additionally, while previous 2-SNAP demonstrations have added external choke inductance to stabilize the avalanching photocurrent, we show that the external inductance can be entirely folded into the active area by cascading 2-SNAP devices in series to produce a greatly increased active area. We fabricated two types of series-2-SNAP circuits, one with short and the other with long nanowire lengths (4 ?m and 20 ?m, respectively) with cascades of 2-SNAPs to create the choke inductance. For both cases, we observed that 1) the device efficiency achieved complete saturation, and 2) the 40 nm 2-SNAP circuit critical current was approximately twice that for a 40 nm non-SNAP configuration. Finally, we extended the series-2-SNAP concept by putting two series-2-SNAPs in parallel to make a 192 ?m^2 large area device — nearly 200 times larger than the base unit 2-SNAP and nearly 5 times larger than a typical non-SNAP – that achieved high system detection efficiency with two-fold increase in SNR and an approximately four-fold increase in the critical current compared to an 40 nm non-SNAP.

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9492-14, Session 5

Multi-channel single photon receiver for IceSat-2 Mission ATLAS instrument *(Invited Paper)*

Guangning Yang, Michael A. Krainak, Xiaoli Sun, NASA Goddard Space Flight Ctr. (United States); Wei Lu, As and D, Inc. (United States); William E. Hasselbrack, Sigma Space Corp. (United States)

Photon-counting detectors are required for the NASA (ICESat2 – Ice, Cloud and land Elevation Satellite-2) Advance Topographic Laser Altimeter System (ATLAS). The ATLAS receiver uses six multichannel photon counting detectors - one for each of six distinct optical beams. It requires a photon counting detector with high counting efficiency at 532 nm (>15%), large dynamic range (from greater than 12 photons per pulse to a 0.01 photons per pulse), low jitter (less than 285ps), short dead time (<3 ns), long lifetime under large solar background radiation, radiation hard for space operation, and ruggedized for survives the harsh vibration during the launch. A Hamamatsu photomultiplier with a 4x4 array anode (Fig. 1) was selected for IceSat2 to meet these requirements.

In this paper, we will present the photon counting detector selection, the design and performance of the constant fraction comparator circuit for precision timing, detector lifetime test and verification, detector high power damage level test and verification.

We will describe our measured data for addressing each mission requirement. A constant fraction discriminator timing circuit design was adopted to achieve <250 ps jitter (Fig. 2) and dead time less than 3 ns. The multi-anode PMT achieves large dynamic range while each counting channel operates at less than one photon per pulse to minimize the first photon timing bias. An accelerated PMT Lifetime life time test was conducted and proved the detector meets the mission lifetime requirement (4 years with an average count rate of 2.5 MCPS). An extended green wavelength sensitive cathode was selected for greater than 15% detection efficiency at 532 nm. A ruggedized PMT mechanical housing design was used to space qualify the PMT with a greater than 10 grms vibration requirement. A PMT overlight damage level test was conducted and proved that the PMT will survive under an exposure of 3 ms, 10 KHz burst pulse stream with greater than 2 uJ per pulse and a 500 ps pulse width (4,000W peak power).

The ATLAS flight receiver with 60 primary channels and 60 redundant (cold spares) channels is fully built and delivered to ATLAS instrument for integration.

9492-15, Session 5

Photon counting using maximal length sequences: a theoretical assessment of pseudo-random coding for rangefinding *(Invited Paper)*

Robert A. Lamb, SELEX ES (United Kingdom)

Time-of-flight (TOF) single photon counting lidar has made tremendous progress in recent years and is the subject of intense development for both land based and airborne rangefinding and terrain mapping applications. Early demonstrations of TOF over distances of several kilometres used fixed repetition rates to derive the absolute range or the range (depth) profiles of extended targets. The need to maintain a high data rate to reduce data acquisition times at ranges greater than c/2fPRF, where fPRF is the pulse repetition frequency, led to the attendant problem of range aliasing. This was subsequently solved by using random waveforms of know patterns: providing the pattern does not repeat during the round trip time to the target, its absolute range can be determined. However, as photon counting is now evolving into integrated 3D imaging lidar, optical communications, rangefinding and designation concepts, the precise statistical nature of random waveforms needs to be defined carefully to ensure optimal performance in TOF lidar or data transmission systems. In this paper, we investigate the use of maximal length (m-) sequences as an example of a deterministic pseudo-random waveform. The m-sequence ensures maximum autocorrelation gain for a given coded bit length. We investigate the use of m-sequences in determining range accuracy as a function of transmit time, range, solar and detector background noise.

9492-16, Session 5

Time-of-flight laser ranging for moving targets with single-photon counting *(Invited Paper)*

Yan Liang, Univ. of Shanghai for Science and Technology (China); Heping Zeng, Univ. of Shanghai for Science and Technology (China) and East China Normal Univ. (China)

With the development of single-photon detection and data acquisition technology, time-of-flight (TOF) ranging systems using time-correlated single-photon counting (TCSPC) technique have been implanted more and more. However, in some typical applications, the velocity of the target is too fast for the TCSPC system to set the short detecting window, leading to difficulties in discriminating the track of the fast moving target, especially in strong background light. Besides, the major weakness in range ambiguity could not be ignored.

We demonstrated coincidence photon-counting laser ranging technique that allows for single-shot measurements on fast-moving objects under strong background light illumination. Coincidences registered by two single-photon detectors within a short time window of 2.4 ns were recorded as the distance information, improving the signal-to-noise ratio to 8.54 dB when the surrounding noise photons caused 5?106 counts/s while the signal pulses contained 10 photons per pulse. Single-shot ranging of both moving and fast position-changing targets was demonstrated with high signal-to-noise contrast at few-photon level.

Furthermore, we illustrated a TOF ranging system employing laser pulses at 1550 nm with multiple repetition rates to decrease the range ambiguity. The TSCPC with an InGaAs/InP avalanche photodiode based single-photon detector, was applied to record different arrival time of the scattered return photons from the non-cooperative target at different repetition rates to determine the measured distance, providing an effective and convenient method to increase the absolute range capacity of the whole system. We attained hundreds of meters range with millimeter accuracy by using laser pulses of approximately 10-MHz repetition rates.

9492-17, Session 5

Underwater depth imaging using time-correlated single photon counting

Aurora Maccarone, Aongus McCarthy, Ximing Ren, Ryan E. Warburton, Andrew M. Wallace, Heriot-Watt Univ. (United Kingdom); James Moffat, Defence Science and Technology Lab. (United Kingdom); Yvan R. Petillot, Gerald S. Buller, Heriot-Watt Univ. (United Kingdom)

We investigate the potential of a depth imaging system for underwater environments. This system is based on the time-of-flight approach and the time correlated single-photon counting (TCSPC) technique. We report laboratory-based measurements and explore the potential of achieving sub-centimetre xyz resolution at 10's meters stand-off distances.

Initial laboratory-based experiments demonstrate depth imaging performed over distances of up to 1.8 meters and under a variety of scattering conditions. The system comprised a monostatic transceiver unit, a fiber-coupled supercontinuum laser with a wavelength tunable acousto-optic filter, and a fiber-coupled individual silicon single-photon avalanche diode (SPAD). The scanning in xy was performed using a pair of galvonometer mirrors directing both illumination and scattered returns via a coaxial optical configuration. Target objects were placed in a 110 litre capacity tank and depth images were acquired through approximately 1.7 meters of water containing different concentrations of scattering agent. Depth images were acquired with a 150 ?m spatial resolution in clear and highly scattering water using per-pixel acquisition times in the range 0.5-100 ms at average optical powers in the range 0.8 nW to 120 ?W.

Based on the laboratory measurements, estimations of potential performance, including maximum range possible, were performed with a model based on the LIDAR equation. These predictions will be presented for different levels of scattering agent concentration, optical power, wavelength and comparisons made with naturally occurring environments. The experimental and theoretical results indicate that the TCSPC technique has potential for high-resolution underwater depth profile measurements.

9492-18, Session 6

Real-time imaging and tracking of objects hidden from view using SPAD imaging arrays *(Invited Paper)*

Daniele Faccio, Genevieve Gariepy, Francesco Tonolini, Heriot-Watt Univ. (United Kingdom); Nikola Krstajic, Robert K. Henderson, The Univ. of Edinburgh (United Kingdom); Jonathan Leach, Heriot-Watt Univ. (United Kingdom)

Single photon avalanche diodes (SPAD) arrays are rapidly emerging as a new imaging technology with applications in diverse areas such as time-of-flight imaging and bio-imaging.

We have recently demonstrated the advantages of using silicon based SPAD arrays to perform light-in-flight imaging. Our detector is a 32x32 array of single SPADs, each individually operating in TCSPC mode. The combination of single-photon sensitivity, direct imaging capability of the array and high ?100 picosecond temporal resolution allow to capture the movement of light pulses as they propagate in air by collecting the few photons that are scattered by air molecules.

Here we demonstrate a related technique that relies upon the same features of SPAD arrays. We perform real-time tracking of objects in motion that are hidden from view. As an example, we place an object (a 30 cm high mannequin) behind a wall such that it is completely obscured from the direct line of sight of the SPAD array camera. The multiple spherical-wave reflections of a sequence of laser pulses imaged by the camera appear as circular wave-fronts that evolve and propagate in time following a trajectory that depends on the location of the mannequin. We record this pattern and a retrieval algorithm allows us to reconstruct the location of the object.

Remarkably, we have demonstrated the ability to perform the data acquisition and retrieval in less than one second. This in turn allows to track any object motion in real-time, thus paving the way for a series of novel applications.

9492-19, Session 6

Study of single photon counting for non-line-of-sight vision

Martin Laurenzis, Institut Franco-Allemand de Recherches de Saint-Louis (France); Jonathan Klein, Univ. Bonn (Germany); Andreas Velten, Univ. of Wisconsin-Madison (United States) and Morgridge Institute for Research (United States); Matthias B. Hullin, Univ. Bonn (Germany); Frank Christnacher, Institut Franco-Allemand de Recherches de Saint-Louis (France)

The application of non line of sigh vision has been demonstrated in the recent past on laboratory level with round trip path lengths on the scale of 1 m as well as 10 m. This method uses a computational imaging approach to analyze the scattered information of objects which are hidden from the direct sensors field of view. Recent demonstrator systems were driven at laser wavelengths (800 nm and 532 nm) which are far from the eye-safe shortwave infrared (SWIR) wavelength band i.e. between 1.4 μm and 2 μm. Therefore, the application in public or inhabited areas is difficult with respect to international laser safety conventions.

In the present work, the authors evaluate the application of recent single photon counting devices for non line of sight sensing and give predictions on range and resolution. Further, the realization of a concept is studied enabling the indirect view on a hidden scene. While recent laser gated viewing sensors suffer from a too low temporal resolution due to minimal sensor gate width of around 150 ns, single photon counting devices have high sensitivity and high temporal resolution. Different approaches based on GM-APD and SPAD sensor technologies as well as the lock-in approach of phase-modulated detectors are reviewed. In this publication the authors present detailed theoretical and experimental evaluations.

9492-20, Session 6

Hybrid receiver system for single photon sensitive direct and coherent detection

Piotr K. Kondratko, Paul J. Suni, Andrew T. Bratcher, John J. Glennon III, Lockheed Martin Coherent Technologies (United States)

Hybrid receivers that enable switching between direct and coherent detection provide many imaging functions beneficial to scientific and defense applications. A hybrid receiver system is presented wherein a single detector is switched between the Geiger-mode and linear avalanche modes of operation. This system benefits from enhanced functionality and lower size, weight, power, cost, and complexity than dual receivers implementation. The hybrid receiver sensing modality is reconfigurable on-the-fly between single photon direct detection and amplitude/phase coherent detection. The reconfiguration is achieved by adjusting detector bias (electrically) and by enabling or disabling the local oscillator (optically). In this work, we describe these two sensing scenarios, discuss the operation of the receiver system, and show laboratory-scale imaging results for each mode of hybrid receiver operation.

9492-21, Session 7

Silicon Geiger-mode avalanche photodiode arrays for photon-starved imaging *(Invited Paper)*

Brian F. Aull, MIT Lincoln Lab. (United States)

Geiger-mode avalanche photodiodes (GmAPDs) are capable of detecting single photons. They can be operated to directly trigger all-digital circuits, so that detection events are digitally counted or time stamped in each pixel. An imager based on an array of GmAPDs therefore has zero readout noise, enabling quantum-limited sensitivity for photon-starved imaging applications. In monolithic implementions, the GmAPD is incorporated into the CMOS readout circuit and is fabricated as a part of a standard foundry process. This is a rapid and low-cost fabrication approach, but precludes optimization of APD doping profiles and limits fill factor. MIT Lincoln Laboratory has pursued fabrication of customized APD arrays, which are then hybridized to CMOS readout circuits using bump bonding or 3D integration techniques. These approaches are more difficult and costly than monolithic integration, but allow the APD to be optimized for the intended application. In this presentation, we discuss devices developed for 3D imaging, wavefront sensing, and passive imaging.

9492-22, Session 7

Gun muzzle flash detection using a single photon avalanche diode array in 0.18μm CMOS technology *(Invited Paper)*

Vitali Savuskan, Tomer Merhav, Avi Shoham, Igor Brouk, Yael Nemirovsky, Technion-Israel Institute of Technology (Israel)

In this study, a CMOS Single Photon Avalanche Diode (SPAD) 2D array is used to record and sample muzzle flash events in the visible spectrum, from representative weapons. SPADs detect the emission peaks of alkali salts, potassium or sodium, with spectral emission lines around 769nm and 589nm, respectively. The alkali salts are included in the gunpowder to suppress secondary flashes ignited during the muzzle flash event. The SPADs possess two crucial properties for muzzle flash imaging: (i) very high photon detection sensitivity, (ii) a unique ability to convert the optical signal to a digital signal at the source pixel, thus practically eliminating readout noise. The sole noise sources are the ones prior to the readout circuitry (optical signal distribution, avalanche initiation distribution and non-photonic generation). This enables high sampling frequencies in the kilohertz range without significant SNR degradation, in contrast to regular CMOS image sensors. Narrow band filters around the emission peaks of the alkali salts reduce the contribution of solar radiation. This research will demonstrate the SPAD's ability to accurately sample and reconstruct the temporal behavior of the muzzle flash in the visible wavelength, in the presence of sunlight. The reconstructed signal is clearly distinguishable from background clutter, through exploitation of flash temporal characteristics and signal processing, which will be reported. The frame rate of ~16 KHz was chosen as an optimum between SNR degradation and temporal profile recognition accuracy. In contrast to a single SPAD, the 2D array allows for multiple events to be processed simultaneously. Moreover, a significant field of view is covered, enabling comprehensive surveillance and imaging.

9492-23, Session 7

Analysis and modeling of optical crosstalk in InP-based Geiger-mode avalanche photodiode FPAs

Quan Chau, Xudong Jiang, Mark A. Itzler, Mark Entwitsle, Mark Owens, Krystyna Slomkowski, Princeton Lightwave, Inc. (United States)

Optical crosstalk is an important factor limiting the performances of Geiger-mode avalanche photodiode (APD) focal plan arrays (FPAs). This is especially true for APD arrays with increased pixel density. For arrays of the same format, FPA operating at 1.55um has a more severe crosstalk issue compared to a FPA operating at 1.06 um. Different approaches such as etched trenches and epitaxially grown filter layers have been adopted to mitigate crosstalk effect. We have performed extensive experimental and theoretical investigations on the crosstalk effects in InP-based Geiger-mode APD FPAs. We will present a detailed spatial and temporal analysis of crosstalk on both 32x32 and 128x32 operating at different wavelengths

(1.06 um and 1.55 um). Different optical paths contributing to crosstalk have been identified and their relative contributions quantified. Our study of crosstalk characteristics is based on the dark count events in FPAs, and we have developed an algorithm to identify the prime pixels that trigger crosstalk events and effectively separate crosstalk events from intrinsic dark count events. A numerical model is also developed to predict the crosstalk probability of a Geiger-mode APD FPA. This model takes into account a full range of parameters representing Geiger-mode APD array's design and operating conditions.

9492-24, Session 7

Model of turn-on characteristics of InP-based Geiger-mode avalanche photodiodes suitable for circuit simulations

George Jordy, Joseph P. Donnelly, MIT Lincoln Lab. (United States)

A model for the turn-on characteristics of separate-absorber-multiplier InP-based Geiger-mode avalanche photodiodes has been developed. Verilog-A was used to implement the model in a manner that can be incorporated into circuit simulation. This approach solves the first order nonlinear differential equations that govern the avalanche current of the APD, rather than using SPICE elements to mimic the voltage and current characteristics of the APD. This continuous time representation is fundamentally different than the piece wise linear characteristics of other models. The model is based on a driving term for the differential current, which is given by the voltage overbias minus the voltage drop across the device's space-charge resistance RSC. This voltage drop is primarily due to electrons transiting the separate absorber. RSC starts off high and decreases with time as the initial breakdown filament spreads laterally to fill the APD. With constant voltage bias, the initial current grows exponentially until space charge effects reduce the driving function. With increasing current the driving term eventually goes to zero and the APD current saturates. When discharging an external capacitor circuit, the driving term becomes negative as the capacitor discharges, reducing the current and driving the voltage below breakdown. The model parameters depend on device design and are obtained from fitting the model to Monte-Carlo turn-on simulations that include lateral spreading of the carriers of the relevant structure. The Monte-Carlo simulations also provide information on the probability of avalanche, and jitter due to where the photon is absorbed in the APD.

9492-25, Session 7

Low noise InGaAs/inp single-photon negative feedback avalanche diodes: characterization and applications *(Invited Paper)*

Gianluca Boso, Boris Korzh, Tommaso Lunghi, Hugo Zbinden, Univ. de Genève (Switzerland)

In recent years, many applications have been proposed that require detection of light signals in the near-infrared range with single-photon sensitivity and time resolution down to few hundreds of picoseconds. InGaAs/InP single-photon avalanche diodes (SPADs) are a viable choice for these tasks thanks to their compactness and ease-of-use. Unfortunately, their performance is traditionally limited by high dark count rates (DCRs) and afterpulsing effects. However, a recent demonstration of negative feedback avalanche diodes (NFADs), operating in the free-running regime, achieved a DCR down to 1 cps at 10 % photon detection efficiency (PDE) at telecom wavelengths.

Here we present our recent results on the characterization of the DCR, afterpulse probability and the PDE of NFAD detectors for temperatures down to 143 K. The PDE was measured with 1% accuracy using a simple radiometer based on an Erbium-Doped-Fiber-Amplifier. A FPGA controlled test-bench facilitates the acquisition of the afterpulsing probability over three orders of magnitude in time.

We also demonstrate the performance of the detector in different applications: In particular, with low-temperature NFADs, we achieved quantum key distribution over 300 km of ultra-low loss fiber. But low noise InGaAs/InP SPADs will certainly find applications in yet unexplored fields like photodynamic therapy, near infrared diffuse optical spectroscopy and many more. For example with a large area detector, we made time-resolved measurements of singlet-oxygen luminescence from a standard Rose Bengal dye in aqueous solution.

9492-26, Session 7

Al0.8Ga0.2As avalanche photodiodes for single photon counting

Min Ren, Yaojia Chen, Wenlu Sun, Joe C. Campbell, Univ. of Virginia (United States); Xiao Jie Chen, Erik B. Johnson, James F. Christian, Radiation Monitoring Devices, Inc. (United States)

In this work, we report Al0.8Ga0.2As single photon avalanche diodes (SPADs). Linear-mode Al0.8Ga0.2As APDs have exhibited low excess noise (k = 0.13) and low dark current density of ~179nA/cm2 at gain as high as 200 at room temperature. Geiger mode performance was measured with a capacitance-balanced gated quenching circuit. A 405 nm pulsed laser diode, with pulse-width of 3 ns, was used as the light source. The breakdown voltage is 20.5 V at room temperature and the gate pulse was fixed at 2 V for all measurements with a pulse-width of 5 ns. The external quantum efficiency is 10% at 405 nm. After pulse probabilities (APP) and dark count probabilities (DCP) of SPADs, with diameter from 30 μm to 150 μm, are characterized and compared at single-photon-detection-efficiency of 5%. With 1 μs hold-off time after pulse probability = 1.36% and dark count probability = 2.99x10^(-5) per gate was achieved at room temperature.

9492-27, Session 8

Nanopillar optical antenna avalanche detectors: 3D nanoscale electric fields for high speed, low noise avalanche gain *(Invited Paper)*

Pradeep N. Senanayake, Alan Farrell, Diana L. Huffaker, Univ. of California, Los Angeles (United States)

This talk will focus on the design, fabrication and electro-optic characterization of a novel detector architecture "3D Nanopillar Optical Antenna Avalanche Diodes" (3D-NOAADs) for shrinking both the absorption and multiplication volumes using III-V nanopillars, while enhancing the optical absorption via a self aligned 3D plasmonic antenna. Wavelength tuning and hybridization of the optical absorption via Surface Plasmon Polariton Bloch Waves (SPP-BWs) and Localized Surface Plasmon Resonances (LSPRs) will be discussed. Photo-generated carrier transport from the absorption region into the multiplication region and subsequent impact ionization will also be discussed. The first measurement of excess noise factor in nanostructured photodiodes will be presented. Single pixel 3D-NOAADs exhibit substantially lower excess noise factors compared to bulk (keff ~ 0.13), low breakdown voltages ~ 8 V and gain-bandwidth products ~ 200 GHz.

9492-28, Session 8

Visible to infrared photon counting with the MWIR HgCdTe e-APD *(Invited Paper)*

William W. Sullivan III, Jeffrey D. Beck, Richard Scritchfield, Mark R. Skokan, Pradip Mitra, DRS Technologies, Inc. (United States); Xiaoli Sun, James B. Abshire, NASA Goddard Space Flight Ctr. (United States); Darren P. Carpenter, Barry L. Lane, Analog/Digital Integrated Circuits, Inc. (United States)

An updated review of improvements in the understanding and maturity of linear mode photon counting with HgCdTe electron-initiated avalanche photodiode (APD) focal plane arrays (FPAs) is presented. This work was done under a NASA Advanced Component Technology (ACT) program. The program's goals were to understand limitations discovered in DRS' first successful 2x8 linear mode photon counting (LMPC) FPA reported in the 2011 paper. A process validation lot of 2x8 FPAs was fabricated. Five FPAs were characterized that replicated the 2011 LMPC 2x8 FPA with photon counting sensitivity. It was experimentally verified that readout integrated circuit (ROIC) glow emitted photons was responsible for most of the false event rate (FER) of the 2011 array. The application of a single layer metal blocking layer between the ROIC and the detector array and optimization of the ROIC biases reduced the FER by an order of magnitude. Further improvements that implement blocking layers in the ROIC are expected totally eliminate this issue and bring the FER down to the < 20 k e/s gain normalized dark current levels measured on adjacent APD test pixels. Photon detection efficiencies (PDEs) of greater than 50% were routinely demonstrated across 5 arrays, with one array reaching a PDE of 70%. High resolution pixel-surface spot scans were performed and the junction diameters of the diodes were measured. The junction diameter was decreased from 31 μm to 22 μm resulting in a 4x increase in APD gain from 470 on the 2011 array to 1910 on one of the 2014 FPAs. A 3D Monte Carlo random walk model was generated that showed good agreement with the measured junction diameters, rms jitter, and eCE. Mean single photon signal to noise ratios of over 20 were demonstrated at excess noise factors of 1.2-1.3. A PDE vs. FER model was also generated with good agreement to measured data.

9492-29, Session 8

Recent progress in upconversion detector and its application *(Invited Paper)*

Qiang Zhang, Univ. of Science and Technology of China (China)

Upconversion detectors utilizing the sum-frequency generation (SFG) in periodically poled lithium niobate (PPLN) waveguides or bulk crystals to convert the telecom band wavelength into near infrared window and then detect it with Silicon APD. Generally, upconversion detector has high detection efficiency but too many noise counts.

In this talk, we shall show that with long wave pump and narrow band filtering technology, we can reduce the noise count rate 100 cps, as low as the intrinsic noise level of a Silicon APD based SPD with a 28% system detection efficiency. Based on this new upconversion detector, we implemented several quantum key distribution experiment, including, 52 km day light quantum communication, measurement device independent QKD and passive decoy QKD. Meanwhile, the detector has been used to achieve 217 km optical time-domain reflectometry (OTDR) and measure air visibility.

In the end of the talk, we shall discuss and show some preliminary results about how to make the whole upconversion system compact and how to increase its detection efficiency.

9492-30, Session 8

Phase preservation and ultra-low background in parametric up-conversion at the single-photon level

Yu-Hsiang Cheng, Tim O. Thomay, Joint Quantum Institute (United States) and National Institute of Standards and Technology (United States); Alan L. Migdall, Glenn S. Solomon, Joint Quantum Institute (United States) and National Institute of Standards and Technology (United States); Sergey V. Polyakov, Joint Quantum Institute (United States) and National Institute of Standards and Technology (United States)

We experimentally demonstrate that phase information can be maintained during frequency up-conversion at the single-photon level. Additionally, we show that the up-conversion process may be made noiseless within experimental uncertainty, while maintaining reasonable up-conversion efficiency. Our experimental results are an enabling step towards demonstration of a faithful up-conversion of certain entangled states.

The nonlinear frequency mixing with periodically-poled lithium niobate (PPLN) waveguides is done simultaneously in two arms of a Mach-Zehnder interferometer. A high-power cw 1550 nm pump laser is used to convert near-infrared 920 nm photons into the visible at 577 nm. We choose 920 nm to emulate anti-bunched single-photon sources, such as InAs-based quantum dots (QDs). We detect the up-converted faint state with a Si single-photon avalanche photodiode (SPAD), and use a field-programmable gate array (FPGA) to collect photon statistics. Note that the Si SPADs commonly used for photon detection have significantly higher detection efficiency for visible light as compared to the wavelengths typical of semiconductor QD emission. Furthermore, they are easy to operate at room temperature, comparing favorably to many other types of single-photon detectors. Our laser at 920 nm was attenuated to reach photon flux of 6?10^5 s^-1 to simulate that of typical InAs QD emission.

We observed high contrast fringes with visibility >0.95 with no post-processing. Within the available range of pump powers and using a stock >20 nm bandpass filter around 577 nm, no statistically significant background due to strong pump was detected in our experimental setup.

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9493-1, Session 1

Micro enzymatic biofuel cells: from theoretical to experimental aspect (Invited Paper)

Yin Song, Richa Agrawal, Chunlei Wang, Florida International Univ. (United States)

Miniaturized enzymatic biofuel cells (EBFCs) converting biological energy into electrical energy by using enzyme-modified electrodes are considered as a candidate to power the implantable medical devices and portable electronics. However, low power density and insufficient cell lifetime are two big obstacles to be overcome before EBFCs become competitive in the practical application. In this work, we demonstrated an EBFC system employing 3D micropillar arrays integrated with graphene/CNT composite. The fabrication process of this system combines top-down carbon microelectromechanical system (CMEMS) technology to fabricate the 3D micropillar arrays platform and bottom-up electrophoretic deposition (EPD) to deposit graphene/CNTs/enzyme composite onto the 3D micropillar arrays. The electrode characterization and cell performance evaluation have been conducted by cyclic voltammetry, scanning electron microscope, fourier transform infrared spectroscopy, etc. In addition, the theoretical simulation of this EBFC system is conducted using finite element analysis from COMSOL 4.3a in terms of cell performance, efficiency and optimum cell configurations. In order to maximize the power output of the EBFC, within the same cell configuration, the energy generated from enzymes could be accumulated first at the charging process and then dissipated in a short time with higher power to the external circuit. The comparison of full cell electrochemical performance of the EBFC system between before and after self-charging process will be also presented in this talk.

9493-2, Session 1

Performance study of sugar-yeast-ethanol bio-hybrid fuel cells

Justin P. Jahnke, David M. Mackie, Marcus Benyamin, U.S. Army Research Lab. (United States); Rahul Ganguli, Teledyne Scientific Co. (United States); James J. Sumner, U.S. Army Research Lab. (United States)

Renewable alternatives to fossil hydrocarbons for energy generation are of general interest for a variety of political, economic, environmental and practical reasons. In particular, energy from biomass has many advantages, including safety, sustainability, and the ability to be scavenged from native ecosystems or from waste streams. Microbial fuel cells (MFCs) can take advantage of microorganism metabolism to efficiently use sugar and other biomolecules as fuel but are limited by low power densities. In contrast, direct alcohol fuel cells (DAFCs) take advantage of proton exchange membranes (PEMs) to generate electricity from alcohols at much higher power densities. Here, we investigate a novel bio-hybrid fuel cell design prepared using commercial off-the shelf DAFCs. In the bio-hybrid fuel cells, biomass such as sugar is fermented by yeast to ethanol, which can be used to fuel a DAFC. A separation membrane between the fermentation and the DAFC is used to purify the fermentate while avoiding any parasitic power losses. However, shifting the DAFCs from pure alcohol-water solutions to filtered fermented media introduces complications related to how the starting materials, fermentation byproducts and DAFC waste products affect both the fermentation and the long-term DAFC performance. This study examines the impact of separation membrane pore size, fermentation/fuel cell byproducts, alcohol and salt concentrations, and load resistance on fuel cell performance. Under optimized conditions, the performance obtained is comparable to that of a similar DAFC run with a pure alcohol-water mixture. Additionally, the modified DAFC can provide useable amounts of power for weeks.

9493-3, Session 1

Synergic system between photovoltaic module and microbial fuel cell with simultaneous pollution control

Oresta M. Vasyliv, Arterium Corp. (Ukraine); Neelkanth G Dhere, Univ of Central Florida (United States)

Solar energy is ultimately the long-term solution of renewable energy production without a net carbon dioxide emission, but its efficacy depends on how this source of energy is harvested. The sun does not shine all day, nor does it shine equally in all regions. Thus, solar panels can help with daytime large electricity needs, but it will not serve as a basic source of energy throughout the day and night without an efficient methods of energy storage. Microbial fuel cell (MFC) is not dependent on the day time and thus their application for derivation of energy is more universal. Although power efficiency of these systems is lower in comparison with photovoltaic (PV) panels. Joining of MFC and PV modules will allow in obtaining energy round the clock. Low efficiency of MFC will be increased because of energy accumulated by photovoltaic system during the daytime. Thus, usage of energy generated by MFC during the nighttime and PV power during the daytime results in a complementary synergic system with the prospect of non-stop stable power generation.

Desulfuromonas. acetoxidans is exoelectrogenic sulfur-reducing bacteria that is shown to be effective anode biocatalyst in MFC. Recently it was determined that despite H2S generation as a result of S0-reduction, this bacterium can also oxidize elemental sulfur to sulfite and sulfate with an electrode serving as the electron acceptor. Since sulfur can accumulate on anodes from the abiotic oxidation of sulfide it shows the possibility of continuous simultaneous carrying of opposite stages of sulfur cycle in the anode chamber of MFC by activity of only one genus of bacterium. Hence simultaneous sulfur redox reactions supported by D. acetoxidans activity doubles the electron transfer to the electrode, which can lead to increase the effectiveness of MFC power output. It was shown that D. acetoxidans is resistant to different concentrations (in the range of 0.5-2.5 mM) of copper, iron, nickel, lead etc. Using metal-resistant strains of these bacteria helps overcome H2S toxicity (which is the final product of bacterial dissimilative sulfur-reduction), since divalent cations will interact with sulfide ions, forming insoluble precipitates. Thus D. acetoxidans may be applied for remediation of toxic metal ions from water environments because of metal fixation in form of insoluble complexes of metal sulfides. It has been shown that D. acetoxidans is capable of converting the organic compounds, such as malate, pyruvate, succinate, fumarate, ethanol, butyrate etc. It shows the possibility of its usage for decreasing the organic content in effluents while application in MFC with formation of simple benign constituents, such as CO2 and H2O. It is followed by water purification with the simultaneous energy production.

Application of PV-MFC system could be one of the modes of highly effective eco-friendly energy derivation with simultaneous reduction of organic and inorganic waste of water environment. Joining the MFC and PV system will allow establishment of new self-functioning effective energy-production system.

9493-4, Session 1

Inhomogeneous thermoelectrics: improving overall ZT by localized property variations

Narasimha S. Prasad, NASA Langley Research Ctr. (United States); David C. Nemir, Jan Beck, TXL Group, Inc. (United States); Jay R. Maddux, Patrick J. Taylor, U.S. Army Research Lab. (United States)

The search for improved thermoelectric materials is driven in part by the desire to convert otherwise wasted low-temperature heat into useful electricity. In this work, we demonstrate a new path towards materials having higher overall ZT, and consequently improved capacity to obtain more electrical power from a given content of heat. We produced alloys of $(Bi,Sb)_2Te_3$ using a special gas atomization process that is capable of producing source powder material having nanometer-scale grain size. When impulse-compacted by shockwave consolidation, the obtained dense solid will retain its nanostructure because insufficient time and temperature are available for the kinetics of any appreciable grain growth to proceed. However, if there is initial non-uniformity in the properties of the source powder, or if there is stress non-symmetries during shockwave consolidation, then the obtained consolidated material may have locally inhomogeneous properties distributed throughout the material. Thermoelectric property measurements from selected regions within the consolidated sample indicate a wide distribution of properties. For example, the thermal conductivity at room temperature ranged from as low as 1.30 Watts/m-K in one region to higher than 3.00 Watts/m-K in a neighboring region. The electrical resistivity showed similar variation from as low as 0.5 m Ohm-cm to as high as 1.5 m Ohm-cm. Individually, those regions exhibited thermoelectric ZT values ranging between 0.3 and 0.4 . However, when combined into a dense nanocomposite, the overall ensemble ZT = 0.6 which is nearly a factor of 2 higher.

9493-5, Session 1

Solar fuel production for a sustainable energy (Invited Paper)

Deryn D. Chu, U.S. Army Research Lab. (United States); Nick Wu, West Virginia Univ. (United States); Terry DuBois, Edward J. Plichta, U.S. Army RDECOM CERDEC NVESD (United States)

Sun light is the most abundant renewable energy source and has great potential to meet future global energy demands. Solar fuels that convert solar energy to chemical energy stored as chemical fuels such as hydrogen and methanol. Converting sunlight with water and carbon dioxide into solar fuels, without competing with food production, is an important route for sustainable development beyond fossil fuels. The direct photoelectrochemical water splitting to generate hydrogen has attracted attention world-wide due to their renewable fuel generation and benefit to the environment. Recently, numerous researchers have focused on artificial photosynthesis to convert sunlight, water and CO_2 to organic fuels. The products derived from carbon dioxide reduction varies and includes methane, formic acid, methanol, etc., which depends on the reaction conditions. Using the photoelectrochemical technique, the photoelectrodes combine with catalysts enhancing reaction rates. The photo-electrochemical conversion of water to hydrogen and CO_2 to small organic molecules as fuels has great potential to become a viable and economical technology. In this presentation, enhanced photocatalytic reactions through extended light absorption will be discussed.

9493-6, Session 2

Dielectric properties of low temperature nano engineered Y2/3Cu3Ti4O12 ceramic compound

K. D. Mandal, Sunita Sharma, Shiv S. Yadav, Institute of Technology, Banaras Hindu Univ. (India); M. M. Singh, Narsingh B. Singh, Univ. of Maryland, Baltimore County (United States)

Non-ferroelectric material exhibiting high dielectric constant with good thermal stability and low dielectric loss is the most important prerequisites for the fabrication of noble ceramic material which is suitable for capacitor, resonator and filler applications in electronic devices. Normally size and performance of such electronic devices can be regulated by their material properties. The size of the ceramic could be remarkably reduced as the size of the resonator, is inversely proportional to the square of dielectric constant of the material. Further, the dielectric constant of the material should be independent of temperature and frequency.

9493-7, Session 2

Effect of organic flux on the colossal dielectric constant of CCTO

Vishnu Razdan, Carnegie-Mellon Univ. (United States); Abhishek Singh, The Pennsylvania State Univ. (United States); Brad Arnold, Fow-Sen Choa, Lisa Kelly, Narsingh B. Singh, Univ. of Maryland, Baltimore County (United States)

The potential demand for miniaturization of electrical and electronic devices has raised a serious challenge for the development of capacitors with high dielectric constant and low loss. The high dielectric constant calcium copper titanate, $CaCu_3Ti_4O_{12}$ (CCTO), and its isomorphs have attracted much attention for the development of promising capacitor materials for electronic industries. Improving the synthetic technology and dielectric properties of these materials is a current focus of research and development in the area of materials chemistry. Because of their improved properties due to size and structure, the nanometer-sized particles (with dimensions smaller than 100 nm) have attracted considerable interest for a wide variety of applications, including electronics, ceramics and as catalysts.

9493-8, Session 2

Mapping capacity loss in Al anodes for ultra-lightweight and compact all-solid-state batteries

Chen Gong, Alex Pearse, Univ. of Maryland, College Park (United States); Dmitry Ruzmetov, National Institute of Standards and Technology (United States) and Univ. of Maryland, College Park (United States); Gary Rubloff, Univ. of Maryland, College Park (United States); Norman C. Bartelt, A. Alec Talin, Sandia National Labs. (United States); Marina S. Leite, Univ. of Maryland, College Park (United States)

All-solid-state Li-ion batteries are a promising and rapidly growing power source for mobile devices. However, the mechanisms of lithiation/delithiation for many anode materials are still not well understood. We investigate the mechanism of lithiation in all-solid-state thin film batteries with Al anodes for ultra-lightweight and compact devices application. We resolve the chemical composition and morphological changes of the anode

upon lithiation by confocal Raman microscopy and X-ray photo-electron spectroscopy (XPS). We find that a Li-Al-O thin layer forms at the top surface of the anode, confirmed by the emerging Raman peaks after cycling at 1380, 1585 cm-1. This oxide layer covers stable LiAl alloy mounds by a surface driven reaction (with (Fd3m) phase, Raman shift at 2890 cm-1). The XPS measurements corroborate the Raman results, showing an atomic ratio of Li:Al equal to 4:1. A simple thermodynamic model for the lithiation of Al suggests that $LiAlO_2$ and Li_5AlO_4 are expected to form at 3.35 V and 0.17 V, respectively, indicating that different Li-Al-O co-exist at the surface of the anode [1]. During lithiation, Li is trapped at the intrinsic Al_2O_3 on the top of the anode, preventing Al diffusion. This unique behavior of Al is caused by Li surface diffusion: Li diffuses ≈ 9 orders of magnitude faster into Si than it does in Al [2]. The addition of a thin and inert metallic cap layer could prevent the surface driven reactions observed, and the design of a new device architecture will be presented.

[1] C. Gong et al. "High spatial resolution imaging of capacity loss in Al anode all-solid-state batteries". In preparation.

[2] M. S. Leite et al. "Insights into capacity loss mechanisms of all-solid-state Li-ion batteries with Al anodes". J. Mat. Chem. A, in press. (2014). DOI: 10.1039/c4ta90112f. Inside Cover.

9493-9, Session 2

Effect of temperature and thickness of the graphene on the hydrogen storage properties

Jie Huang, Chee How Wong, Nanyang Technological Univ. (Singapore)

Hydrogen, of which the application is limited due to the difficulties in finding the ideal storage material, has been considered alternative for petroleum as the main energy source. With its large surface area and other extraordinary physical properties, graphene has been the focus of many researchers as the promising candidate for hydrogen storage and transportation. In this work, the hydrogen storage characteristics of graphene have been investigated by MD simulations. We found that, under a typical environment setup, where the temperature is 70 K and the pressure is 1 MPa, the hydrogen uptake percentage can be as high as 6.51%. And the majority of the hydrogen atoms are absorbed during the initial 100- 200 ps of the simulation. Additionally, the strain energy of the absorbed hydrogen atoms converged to a value with small fluctuation from the initial 100- 200 ps. Moreover, the hydrogen storage properties of graphene with different environment temperatures have been studied as well. We found that with increasing temperature, the hydrogen uptake percentage towards the end of the simulation decrease. Furthermore, the number of layers of the graphene sheet also exerts influence of the hydrogen absorption capability of the sample. We conclude that the more graphene sheets are being used, the less hydrogen atoms are being absorbed by the sample. Our work provides insight into optimizing the environmental temperature and thickness of the graphene sheet when designing novel energy storage devices, especially hydrogen storage devices.

9493-10, Session 2

Hybridization of lithium-ion batteries and electrochemical capacitors: fabrication and challenges (Invited Paper)

Richa Agrawal, Yong Hao, Yin Song, Chunhui Chen, Chunlei Wang, Florida International Univ. (United States)

Conventional electrochemical double-layer capacitors (EDLCs) are well suited as power sources for devices that require large bursts of energy in short time periods. However, when compared to their battery counterparts, EDLCs suffer from low energy densities. The low energy density of EDLCs hinders their applications in devices that require a simultaneous supply of high power and high energy. In order to improve the energy density of EDLCs, the concept of hybridization of lithium-ion batteries (LIBs) and EDLCs has gathered much attention in past years. Such a hybrid is typically referred to as "lithium-ion capacitor" (LIC) or "lithium capacitor" and essentially utilizes a lithium intercalating anode (such as graphite or $Li_4Ti_5O_{12}$) and fast charging-discharging EDLC electrode (such as activated carbon, carbon nanostructures) in a lithium-salt based electrolyte. Although such a system sounds quite ideal in theory, there are major challenges that need to be addressed in order to fully realize the benefits of LIB and EDLC electrodes in conjunction. Most of these challenges stem from the mismatch in capacity of the electrodes and also the charging-discharging times of the electrodes. For instance, the EDLC electrode acts as the limiting factor for the capacity of the system while the LIB electrode limits the power of the system.

Here we have fabricated a hybrid capacitor that utilizes a $Li_4Ti_5O_{12}$ (LTO) based anode and a graphene and carbon nanotube (G-CNT) composite based cathode. LTO is an excellent candidate for LICs because lithium intercalates/de-intercalates at a potential of 1.55V v/s Li/Li+, which is well over the reductive decomposition of the electrolyte. Also, LTO shows little or no volumetric changes with lithium intercalation, which in turn lends it excellent cyclability. Graphene and CNT, on the other hand are both carbon nanostructures and well-known EDLC materials. The active materials were deposited onto copper and aluminum foils, respectively for anode and cathode using electrostatic spray deposition (ESD). Full hybrid cells were assembled using the previously fabricated electrodes keeping in mind the capacity mismatch between the fast charging G-CNT electrode and the lithium-intercalating LTO electrode. Detailed results will be presented at the conference.

9493-11, Session 3

Carbon microelectromechanical systems (C-MEMS) based microsupercapacitors

Richa Agrawal, Florida International Univ. (United States); Majid Beidaghi, Drexel University (United States); Wei Chen, King Abdullah University of Science and Technology (Saudi Arabia); Chunlei Wang, Florida International Univ. (United States)

The rapid development of miniaturized electronic devices has led to a never ending demand for high performance rechargeable micro-power sources. Microsupercapacitors in particular have attracted a great deal of attention in recent years because of their high pulse power and long cycle lives. Carbon microelectromechanical systems (C-MEMS), in which a patterned photoresist is pyrolyzed in an inert environment at a high temperature is a powerful approach to fabricate high aspect ratio carbon microelectrode arrays, which have been proved to hold great promise as a platform for energy storage. Additionally, different active materials can be loaded onto these electrode arrays for further enhancement of electrochemical performance. We have explored various techniques, materials and structural designs for micro-supercapacitors. In this talk, C-MEMS based various electrochemical capacitor systems will be briefly introduced. Both two and three dimensional micro-electrodes were fabricated and various electroactive materials were integrated onto the microelectrodes. These include carbon nanotubes (CNTs), polypyrrole and manganese oxide. More recently, we have also examined the integration of Graphene sheets and CNTs onto the micro-electrodes as promising high power and energy density material.

9493-12, Session 3

Paper-based broadband and wide-angle antireflection coatings for Si and GaAs solar cells

Dongheon Ha, Jeremy N. Munday, Univ. of Maryland, College Park (United States)

In most of photovoltaic applications, reducing surface reflection is a key

design criterion. Traditionally, researchers have used either single or double-layer antireflection coatings (ARCs) for this purpose; however, these traditional methods require complicated high temperature processes that are costly.

Here we present a simple and easy way to make ARCs based on a micro cellulose fiber paper that reduces light reflection and increases power conversion efficiency. This paper-based ARC has high transmissivity, which enables light to propagate through the transparent paper and reach the active surface. Also, an increased path length in the device will be achieved due to light scattering from the textured composition of the micro cellulose fiber. The paper-based ARC is applied to two different types of solar cells (Si and GaAs), and a broadband and wide-angle optical response is experimentally observed, increasing the efficiency of the GaAs solar cell by ~24% [1]. The effect of the transparent paper ARC on both textured and untextured solar cells is also investigated. This new paper-based ARC with inexpensive and room temperature process can be an excellent candidate to replace conventional ARCs based on expensive and complicated fabrication processes. Furthermore, the transparent paper ARC is made from an earth-abundant and recyclable material, which will cause less environmental issues.

[1] Dongheon Ha, Zhiqiang Fang, Liangbing Hu and Jeremy N. Munday, Adv. Energy Mater., 4: 1301804 (2014): (inside cover)

9493-13, Session 3

High efficiency solar cells utilizing light-trapping structure

Anil Shrestha, Genki Mizuno, Robert Olah, Banpil Photonics, Inc. (United States); Saif Islam, Banpil Photonics Inc. (United States); Achyut K Dutta, Banpil Photonics, Inc. (United States); Nibir K. Dhar, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The absorption of energy from an electromagnetic wave depends on the absorption coefficient of material and the thickness of the sample. At normal incidence, without any back reflector, the material thickness is almost equal to the optical path. If we increase the optical path without increasing the material thickness incorporating nanostructures, then it is possible to achieve the same absorption even using less material thickness. Light trapping is a phenomenon where the incident light goes through multiple reflections inside a device structure having nanostructures, enabling in increasing the optical path, which resulting in high absorption. The nanostructure diffracts the incident radiation and increases the optical path for the electromagnetic radiation. Nanostructures also significantly reduce the reflection from the surface of solar cells which further boosts the absorption at shorter wavelength end of absorption spectrum. At longer wavelength end of absorption spectrum, the light trapping effect significantly increases the optical path leading to expanding and/or increasing the absorption. The modeling and simulation of solar cell having nanostructures are carried out and the simulation results are correlated with experimental results of fabricated test structures.

9493-14, Session 3

Pulsed microwave heating method for preparation of dye-sensitized solar cells for greener, faster, cheaper production of photovoltaic materials

Clifford B. Murphy, Roger Williams Univ. (United States); Robert Cotta, The Univ. of Texas at El Paso (United States); Timothy Blais, Roger Williams Univ. (United States); Charles B. Hall, QD Vision, Inc. (United States)

Microwave heating methods are very popular for developing chemical syntheses that are achieved much more rapidly or with less solvent than via conventional heating methods. Their application to solar cell development has been primarily in developing improvements in the synthesis of dyes and the curing of polymer substrates, but not in assisting the photoanode construction of dye-sensitized solar cells. Microwave heating of conductive substrates can lead to arcing of electricity in the reactor which in turn can lead to damaging the photoanode. Here I present our work in applying a pulsed microwave heating method that affords quicker dye deposition times in comparison to conventional heating (mw 30 min, conventional 60 min) with similar dye concentrations as characterized by UV-Vis absorbance, contact angle measurements, and cyclic voltammetry. Our photoanodes are constructed with anatase TiO2 cured onto FTO glass, deposition of the N719 ruthenium dye either directly to the TiO2 layer or through amide bond formation to a silane layer that has been deposited on the TiO2 layer. Modest improvements in the solar energy conversion efficiency are shown through the microwave method in comparison to conventional heating (mw 0.78% vs. conventional 0.25% reported by K. Szpakolski, et. Al. Polyhedron, 2013, 52, 719-732).

9493-15, Session 3

Energy harvesting via ferrofluidic induction

John G. Monroe, Erick S. Vasquez, Zachary S. Aspin, John D. Fairley, Keisha B. Walters, Matthew J. Berg, Scott M. Thompson, Mississippi State Univ. (United States)

A series of experiments were conducted to verify 'ferrofluidic induction' - a process for generating electrical power via cyclic oscillation of ferrofluid (iron-based or magnetized nanofluid) through or around a solenoid. A capillary-sized, plastic capsule of aqueous ferrofluid was vibrated near 20 Hz through a solenoid which consisted of 600 turns and fabricated from 0.127 mm copper wire. The solenoid was 2.4 cm long and had an internal and external diameter of 1.25 cm and 1.5 cm, respectively. The capsule consisted of 0.75 mL of ferrofluid which consisted of nano-sized (~ 20 nm) iron-oxide particles at a concentration of ~15 mg/mL. Magnetic and morphological properties of the nanoparticles were examined using magnetic force microscopy and transmission electron microscopy, respectively, before and after oscillation experiments. The ferrofluid was actively oscillated with and without a uniform, coaxial, bias magnetic field which was employed to promote alignment of the ferrous nanoparticles' dipoles. For experimental control, a small steel rod (> 1000% more iron) was oscillated through the solenoid. The results indicate that the vibrating, encapsulated ferrofluid induced a +/- 0.4 mV EMF in the solenoid with or without the bias magnetic field present. With the bias magnetic field, the steel rod induced a +/- 10 mV EMF in the solenoid; nearly two orders-of-magnitude greater than the EMF induced without the bias field. These results demonstrate the feasibility of ferrofluidic induction, and secondarily, the importance of an accompanying bias magnetic field. These processes can be exploited to accomplish or enhance energy harvesting and/or conversion in many applications.

9493-16, Session 3

Piezoelectric energy-harvesting power source and event detection sensors for gun-fired munitions

Jahangir Rastegar, Dake Feng, Omnitek Partners, LLC (United States); Carlos M. Pereira, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

This paper presents a review of piezoelectric based energy harvesting devices and their charge collection and storage electronics for use in very harsh environment of gun-fired munitions. A number of novel classes of such energy-harvesting power sources that have been developed for gun-fired munitions and gravity dropped weapons and other similar applications

are also presented together with highly efficient charge collection and storage electronics with integrated event detection and safety electronics and logic. The power sources are designed to harvest energy from firing acceleration and vibratory motions during the flight. The energy harvesting power sources are shown to produce enough electrical energy for many low power fuzing applications and as a component of a hybrid power source to achieve very fast rise time and longer run time. In munitions applications, the developed power sources have the added advantage of providing additional safety, since with such power sources the fuzing electronics are powered only after munitions have exited the barrel and have traveled a safe distance from the weapon platform.

The design of a number of prototypes, including their packaging for high G hardening, and the results of laboratory, air-gun and firing tests are presented. Power sources that generate over 100 mJ in a relatively small packaging for gun-fired munitions have been designed using extensive modeling and finite element analysis and tested at over 40,000 Gs. Methods to increase the efficiency of piezoelectric-based energy-harvesting power sources and to minimize friction and damping losses and development of related testing platforms are discussed.

9493-17, Session 3

C-MEMS for bio-sensing applications

(Invited Paper)

Yin Song, Richa Agrawal, Chunlei Wang, Florida International Univ. (United States)

There is urgent need to develop highly selective, sensitive and reproducible miniaturized bio-sensing platform based on reliable interface that is compatible with microfabrication processing. Our research objective is to advance fundamental research by fabricating pyrolyzed carbon arrays with high surface area as a bio-sensing electrode, developing the functionalization methods to increase biomolecules immobilization efficiency and further understanding electrochemical phenomena occurring at bio/carbon interfaces. The carbon microelectrode arrays with high aspect ratio have been fabricated by carbon microelectromechanical systems (C-MEMS) and nanomaterials such as graphene have been integrated to further increase surface area. To achieve the efficient covalent immobilization of biomolecules, various oxidation and reduction functionalization methods have been investigated. The oxidation treatment in this study includes vacuum ultraviolet, electrochemical activation, UV/Ozone and oxygen RIE. The reduction treatment includes direct amination and diazonium grafting. The functionalized surface has been characterized using XPS, CV and FTIR to confirm and calculate the surface coverage of different functional groups. The developed bio-sensing platform was then applied for several applications, such as: DNA sensor; Glucose sensor; H_2O_2 sensor; Aptamer sensor and HIV sensor. The performance and sensitivity of each biosensor will be discussed in the talk.

9493-18, Session PTue

Interconnection between tricarboxylic acid cycle and energy generation in microbial fuel cell performed by desulfuromonas acetoxidans IMV B-7384

Oresta M. Vasyliv, Arterium Corp. (Ukraine); Olga D. Maslovska, Yaroslav P. Ferensovych, Oleksandr I. Bilyy, Svitlana O. Hnatush, Ivan Franko National Univ. of L'viv (Ukraine)

Desulfuromonas acetoxidans IMV B-7384 is exoelectrogenic obligate anaerobic sulfur-reducing bacterium. Its metal-resistant strains play significant role in heavy metal ions remediation from the aquatic environments because of formation of insoluble metal sulfide precipitates. D. acetoxidans IMV B-7384 was one of the first described electrogenic bacterium that performs complete oxidation of an organic substrate with electron transfer directly to the electrode in microbial fuel cell (MFC). This bacterium is very promising for MFC development because of inexpensive cultivation medium, high survival rate and resistance to various heavy metal ions. Its comparatively small size (0.4-0.8?1-2 ?m) is highly beneficial while application of porous anode material. Complete bacterial cover of an electrode area significantly improves the effectiveness of its usage. Two chamber MFC with volume 0.3 l was constructed with application of D. acetoxidans IMV B-7384 as anode biocatalyst. The initial biomass of bacterial suspension was 0.30±0.05 g of dry cell weight per liter. The interconnection between the reductive stage of tricarboxylic acid (TCA) cycle, which functions under anaerobic conditions, and MFC performance was established. Malic, pyruvic, fumaric and succinic acids in concentration 42 mM were separately added into the anode chamber of MFC as the redox agents. Application of malic acid caused the most stable and the highest power generation in comparison with addition of pyruvic, fumaric and succinic acids. The maximal power density (10.07±0.17mW/m2) was observed on 136 hour of bacterial cultivation under addition of malic acid while increasing of growth time up to 480 hour caused decrease of power density by 25%. Under addition of pyruvic, succinic and fumaric acids into the anode chamber of MFC the maximal power density values equaled 5.80±0.25 mW/m2; 3.2±0.11mW/m2, and 2.14±0.19 mW/m2 respectively on 40, 56 and 32 hour of bacterial cultivation. On 480 hour of D. acetoxidans IMV B-7384 growth the generated power decreased by 71%, 88%, and 27 % respectively under application of pyruvic, succinic and fumaric acids. Hence the malic acid conversion via reductive stage of TCA cycle is shown to be the most significant process in terms of electricity generation in MFC by D. acetoxidans IMV B-7384 under anaerobic conditions.

9493-19, Session PTue

Alloyed metal nanoparticles with modulated optical properties for photovoltaics

Allen Chang, Chen Gong, Ellen Cesewski, Marina S. Leite, Univ. of Maryland, College Park (United States)

Plasmonic pure metal nanostructures have been shown to improve the efficiency of solar cells by increasing light scattering. In particular, extensive efforts have been dedicated to understand how Ag nanoparticles enhance light absorption within photovoltaic devices and recently, Al has emerged as a potential candidate for increasing light absorption at short wavelengths. However, these current plasmonic pure metal nanoparticles suffer from limited enhancement capabilities due to their intrinsic optical properties. Here we present the potential for plasmonic alloyed metal nanoparticles formed by a combination of Ag, Al, Au and Cu to increase solar cell efficiencies beyond the enhancement by pure metals. We fabricate arrays of metallic alloyed nanoparticles by physical deposition methods with controlled sizes (down to 100 nm) and extremely high yield (> 95%). We modulate the optical properties of the nanostructures by varying alloy compositions, achieved by sequential/alternating e-beam evaporation of 5 nm layers of different metals and by co-sputtering. We incorporate the alloyed nanoparticles into GaAs solar cells and locally measure the spectrally dependent photocurrent and open circuit voltage enhancements by near-field scanning optical microscopy. Our results show increased optical activity surrounding the nanostructures and spectral dependence, only revealed by the high spatial resolution measurements performed here. Furthermore, our Mie scattering calculations suggest that alloyed metals, Al_xAg_{1-x}, show low optical loss – therefore increased power conversion efficiency – over the bulk of the sun spectrum (280 nm - 1480 nm). Thus we can enhance light absorption into a solar cell device over a wider wavelength range than pure metals.

9493-20, Session PTue

A new scattering and absorption enhancement mechanism using quantum dot emission

Yunlu Xu, Jeremy N. Munday, Univ. of Maryland, College Park (United States)

Recently, significant attention has been given to metallic and dielectric scattering structures to enhance the absorption within the active semiconductor layer of a device. These scattering structures have improved the performance of both detectors and solar cells; however, metallic structures suffer from Ohmic losses and dielectric scatterers have poorer scattering efficiencies. Here, we demonstrate that a thin quantum dot layer can be used to effectively absorb the incident light and radiate it into specific modes of the semiconductor to enhance the absorption within the active layer. Our device consists of a thin-film photovoltaic cell with a back reflector containing a uniformly distributed quantum dot layer within a periodic array of aluminum nanostructures. The aluminum nanostructures serve to aid in the coupling of the quantum dot emission into waveguide modes of the structure and also to transport carriers to the back electrode. We studied the impact of the size and periodicity of nanostructures on photon absorption and coupling efficiency into the fundamental modes of the structure. We applied this architecture to a polymer photovoltaic device and demonstrated an increased coupling efficiency to the active layer. We also studied the thickness dependence of this structure and found significant device performance improvement for thicknesses below 100 nm. Our analysis shows that the absorption of an ordinary polymer photovoltaic device is increased by ~30% using this technique [1].

[1] Y. Xu and J.N.Munday, Opt. Exp., 22, A259-A267 (2014)

9493-21, Session PTue

Power conversion and photodetection through hot carrier generation and collection in a TCO-insulator-metal based device

Tao Gong, Jeremy N. Munday, Univ. of Maryland, College Park (United States)

Hot carrier devices, which take advantage of generated electrons with high kinetic energy before relaxation, have been drawing increased interest recently. As a result of plasmonic-enhanced absorption in nanostructured metals, photodetectors based on metal-semiconductor junctions have been exploiting hot electron effects to allow sub-bandgap absorption and hence show promise as near IR wavelength detectors. Here we present a simple transparent conductive oxide (TCO)-insulator-gold based junction that allows for the generation and collection of hot carriers in the visible wavelength range. Experimental hot carrier generation and extraction is observed for both monochromatic and broadband illumination. In addition, the absorption is independent of illumination angle for incidence angles up to 60°. The photo-generated current is nearly constant under bias conditions of +/- 0.2 V, which suggests the device can be used a stable photodetector even under external bias. A theoretical model is also developed and explains the experimental data well. Moreover, we predict an over 10% power conversion efficiency for an optimized device.

9493-22, Session PTue

The electrical and structural analysis of degraded single junction amorphous silicon solar modules

Gilbert O. Osayemwenre, Univ. of Fort Hare (South Africa)

This paper outline a systematic approach used in evaluating the quality, performance and reliability of single junction amorphous silicon solar modules (a-Si:H). The analytical techniques include an electrical and structural analysis. These techniques were used to obtain a holistic view of the state of affairs of these readily available PV modules for small stand-alone systems. Specifically, current-voltage (I-V) characterization and scanning electron microscopy (SEM) will be presented as diagnostic tools in this article. The SEM (JEOL, JED-2300) was used to study the surface morphology of the affected region, results show structural damage in the affected regions. The experiment shows that the energy output of the modules varies a degradation variation of 2.5% to 25.7%, was observed. The detailed results will be presented in the final paper.

In conclusion, this research established the degradation which occurs and correlate it to the morphological damage. The module with the worst case scenario has an efficiency of 59% decrease, this could be unacceptable in a device where stability is of priority.

9493-23, Session PTue

Spray-on solar cells using non-toxic nanocrystal inks

Troy K. Townsend, Harry K. Kelderman, St. Mary's College of Maryland (United States)

Solution processed solar cells were fabricated from nanocrystal inks in air under ambient conditions to produce non-toxic devices made entirely from a spray process. Transparent electrodes of indium tin oxide (ITO) were deposited onto non-conductive glass from a combustion process followed by visible light absorbing (band gap = 2.5 eV) CoO nanocrystals (p-type) and ZnO nanocrystals (n-type). The heterojunction device was completed with a thiol-stabilized Au (2-3 nm) ink, and the entire device (glass/ITO/ZnO/CoO/Au) was annealed at 400oC to promote sintering and measured with 1 sun illumination. Device films were characterized with XRD, UV/Vis, and SEM to compare deposition techniques. Film morphologies were found to be directly related to device performance, and spray-cast device films were found to be comparable to spin-cast layers. Spray-deposition offers unique advantages for producing electronic devices on large or irregular surfaces.

9493-24, Session PTue

How effective are Lambertian dielectric scatterers for light trapping?

Joseph Murray, Jeremy N. Munday, Univ. of Maryland, College Park (United States)

To reduce costs and decrease recombination losses, many photovoltaic technologies are shifting toward thin-film devices. The need for complete light absorption however constrains reduction in thickness. Light trapping can be applied to increase absorption in thinner devices. Of the many light trapping strategies, adding a random dielectric scatterer to a photovoltaic device is a simple, cost effective way to increase the performance of solar cell devices. However, coatings which show excellent performance as scatterers don't generally enhance device absorption as much as the ideal Lambertian would predict. The interface between such a coating and the device greatly effects the scattering into the cell. These interfaces differ from the ideal Lambertian in both amount and directionality of scattering. Here, using a novel measurement technique, we demonstrate this difference from both the ideal Lambertian and frequently employed models. The Ideal Lambertian model significantly overestimates the scattering and commonly used models cannot correctly account for the reflectance. We further extend this study to show that these simple approaches create poor predictions of device absorption. We show that even a high quality scatterer can quickly deviate from Lambertian when light is not normally incident upon the coating. This result is used to illustrate the need for careful consideration when predicting the device performance of light trapping structures. Finally,

we will show ways to improve traditional light trapping structures and discuss design considerations for surpassing traditional light trapping limits.

9493-25, Session PTue

Enhanced vibration energy harvesting using nonlinear oscillations

Emily K. Engel, Jiaying Wei, Christopher Lee, Franklin W. Olin College of Engineering (United States)

Results are presented for the design, fabrication, and testing of a novel electromagnetic-based device concept to convert ambient mechanical vibration into electricity. In order to harvest energy over a greater frequency range (as compared to that of single-natural-frequency devices), a tuned L-shaped beam is used as a mechanical transducer to generate nonlinear oscillations. The first two natural frequencies of the L-beam are the first bending modes of the horizontal and vertical legs of the L-beam, respectively. They are tuned to a (near) 2:1 ratio. Under harmonic base excitation, an autoparametric, dynamic response can result in which one externally excited vibration mode parametrically excites a second vibration mode resulting in significant displacement of both modes (beams) over an extended frequency range. A series of demonstration devices were built and measurements were taken to determine system configurations that maximize power generation.

The geometry of an L-shaped beam with adjustable end mass (magnets) at the free end of the vertical leg was designed guided by finite element analysis such that the first two natural frequencies occurred in a (near) 2:1 ratio. This ratio was verified by impact hammer testing on prototype devices. Tests were conducted to measure the strain of the vertical and horizontal legs of the harvester along with the current generated in a nearby wire coil in response to single-frequency, harmonic base excitation. Measurements demonstrated that in the cases of near 2:1 ratios, there was a single, stable, harmonic response involving coupled motion of both the horizontal and vertical legs. Corresponding power generated through a load resistor was measured simultaneously. Comparisons between cases where the natural frequencies are tuned and unturned are made. Tuned cases are shown to generate more power over an extended frequency range.

Conference 9494A: Sensors for Next-Generation Robotics II

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9494-1, Session 1

Silicon carbide micro-/nanosystems for sensing and energy applications in harsh environment *(Invited Paper)*

Carlo Carraro, Roya Maboudian, Univ. of California, Berkeley (United States)

Silicon has been the dominant semiconducting material in micro-/nanosystems technologies. However, the material and surface properties of silicon impose limitations on its use in applications involving harsh environment (such as high temperature, high radiation and corrosive conditions). Silicon carbide (SiC), a wide bandgap semiconductor, is emerging as a material to address the limitations of Si as it is temperature tolerant, radiation resistant, and chemically inert. In this talk, I will present recent advances in the materials science and manufacturing technology of SiC thin film and low dimensional structures. This includes deposition, metallization, and fabrication of semiconductor microdevices, with particular emphasis on sensor and energy technologies for applications in harsh environment.

9494-2, Session 1

EHD printing of PEDOT: PSS inks for fabricating pressure sensor arrays on flexible substrates

Joshua R. Baptist, Woo Ho Lee, Dan O. Popa, Muthu B. J. Wijesundara, The Univ. of Texas at Arlington (United States)

Robotic skins with multi-modal sensors are necessary to facilitate better human-robotic interaction in non-structured environments. Integration of various sensors, especially onto substrates with non-uniform topographies, is challenging using standard semiconductor fabrication techniques. Printing is seen as a promising technology that can be explored for sensor fabrication and integration as it may allow direct printing of different sensors onto the same substrate regardless of topology. In this work, we investigate Electro-HydroDynamic (EHD) printing, a method that allows printing of microscale features with a wide array of materials, for fabricating pressure sensor arrays using Poly(3,4-ethylenedioxythiophene):Polystyrene Sulfonate (PEDOT:PSS). Fabrication of such sensors has been achieved by pre-patterning gold metallized interdigitated electrode arrays on a Kapton substrate, with custom PEDOT:PSS ink printed directly onto the electrode arrays. Initial results for the fabricated sensors indicate 4 ohms/newton sensitivity with good linearity between a range of 3 to 15 newton. In the full paper, we will detail the custom PEDOT:PSS ink development as well as electrical, morphological, and mechanical characteristics of the printed sensors while demonstrating the suitability of EHD printing for sensor integration with robotic skin.

9494-3, Session 1

Multi-material additive manufacturing of robot components with integrated sensor arrays

Adam Cohen, Matt Saari, Bryan Cox, Matt Galla, 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 array of sensors as well as 3-D interconnects. However, fabricating a robotic component comprising 100s of distributed, connected sensors (and in some cases, actuators) can be very 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 robotic structural elements with distributed, interconnected sensors and actuators. In essence, we are building a “robot printer” that will automatically produce a pre-assembled, ready-to-use robotic limb or other body part.

The focus is on resistive and capacitive sensors and electromagnetic actuators, though others are anticipated. Our research requires a number of advancements including 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 beyond robotics include advanced prosthetics, wearable electronics, and defense electronics.

This paper will present preliminary results for printing polymers and conductive material simultaneously to form small sensor arrays. Approaches to optimizing sensor performance will also be discussed.

9494-4, Session 1

Micro-force sensing mobile microrobots

Wuming Jing, David J Cappelleri, Purdue Univ. (United States)

This paper presents the first microscale micro force sensing mobile microrobot. The design consists of a planar, vision-based micro force sensor end-effector, while the microrobot body is made from photoresist mixed with nickel particles that is driven by an exterior magnetic field. With a known stiffness, the manipulation forces can be determined from observing the deformation of the end-effector through a camera attached to an optical microscope. After analyzing and calibrating the stiffness of a micromachined prototype, proof of concept tests are conducted to verify this microrobot prototype possessing the mobility and in-situ force sensing capabilities. This microscale micro-Force Sensing Mobile Microrobot (FSMM) is able to translate with the speed up to 10 mm/s in a fluid environment. The calibrated stiffness of the micro force sensor end-effector of the FSMM is on the order of 10^-2 N/m. The force sensing resolution with the current vision system is approximately 100 nN.

9494-5, Session 1

Magnetoresistive sensors for the next robot generation

Rolf Slatter, Sensitec GmbH (Germany)

There is a number of significant new development trends for robots, among others lightweight robots for man-machine interaction, humanoid robots, exo-skeletons and the application of robots in completely new environments e.g. in space.

These development trends are placing new demands on the sensors used to measure the position of the robot joints. These new demands can be summarised as follows:

• Demand for ever more compact design

• Requirements for extreme lightweight design

• Necessity for a large hollow shaft to allow the passage of cables, shafts etc.

• Operation in increasingly difficult operating environments (low temperature, high temperature, radiation etc.)

• Increasing requirements regarding functional safety (at least to Safety Integrity Level (SIL) 3)

These new demands are leading to the increasing use of encoders based on the magnetoresistive (MR) effect. This magnetic sensing principle was first applied industrially in the read-heads of hard disc drives. However, in the past decade the MR effect has been applied successfully to sensors for position, current and magnetic field measurement. MR-based encoders offer a number of benefits compared to the sensor technologies used until now in robot joints. They are significantly lighter than resolvers and allow a large central hollow shaft. They are much more robust than optical encoders, being largely unsusceptible to oil, dust, water and other contaminants. Furthermore they can be operated over a much wider temperature range and with less demanding assembly toleranc-es than optical encoders.

9494-26, Session 1

Force estimation in a 2-DOF piezoelectric actuator by using the inverse-dynamics based unknown input observer technique

Vincent Trenchant, Micky Rakotondrabe, Yassine Haddab, FEMTO-ST (France)

Piezoelectric cantilever actuators are widely used in microrobotic applications such as micromanipulation and serial microassembly thanks to their high bandwidth and high positioning resolution. Microrobotic tasks mainly involve real-time displacement measurement. However, knowing in real-time the force played into role potentially increases the performances and the success rate of the tasks. Measuring both the displacement and the force is however a great challenge in these applications due to the limited space and to the lack of performant but embeddable sensors to carry out the measurement. Observer techniques have been introduced as complementary measurement tools in piezoelectric actuators and proved their efficiency to track the force or the displacements with enough precision and/or enough bandwidth. Nonetheless, these existing works were limited to single degree of freedom (1-DOF) actuators. They cannot therefore be applied to multi-DOF piezoelectric actuators which are increasingly developed these last years. This paper deals with the estimation of force in a 2-DOF piezoelectric actuator, developed in and used as high precision and high dynamics positioner in microrobotic tasks. The actuators exhibit not only hysteresis nonlinearity but also strong couplings properties which add challenge in the observer synthesis. For all that, we propose to adapt the Force estimation in a 2-DOF piezoelectric actuator by using the inverse-dynamics based unkown input observer technique inverse dynamics based unkown input observer (ID-UIO) to estimate the force in the actuator with enough precision and without compromising the bandwidth of measurement, although the presence of the nonlinearity and of the cross-couplings. Experimental tests demonstrate the efficiency of the approach and its interest in force/position controlled positioning tasks.

9494-6, Session 2

Sensor study for high speed autonomous operations

Anne R. Schneider, Zachary La Celle, Alberto Lacaze, Karl Murphy, Robotic Research LLC (United States); Mark Del Giorno, Del Services, LLC (United States); Ryan R. Close, U.S. Army RDECOM CERDEC NVESD (United States)

As robotic systems advance in capabilities and begin to fulfill new roles in both civilian and military life, the limitation of slow operational speed has become a hindrance to the wide-spread adoption of these systems. For example, military convoys are reluctant to employ autonomous vehicles when these systems slow their movement from 60 miles per hour down to 40. However, these autonomous systems must operate at these lower speeds due to the limitations of the sensors they employ. If a vehicle cannot detect an obstacle in sufficient time to act to avoid it, the maximum vehicle speeds must be reduced until the vehicle is able to operate safely. These detections are made even more difficult when moving obstacles and high-risk obstacles—such as human beings—are added to the scenario. Weather conditions, complex terrain, dynamic obstacles, positive and negative obstacles, to name but a few, cause challenges to high speed, autonomous operations.

Robotic Research, with its extensive experience in ground autonomy and associated problems therein, in conjunction with CERDEC/Night Vision and Electronic Sensors Directorate (NVESD), has performed a sensor study to specify system and detection requirements, determine how current autonomy sensors perform in various situations, and analyze how sensors might be employed to increase operational speeds of ground vehicles. These sensors included the state of the art in LADAR/LIDAR, Radar, Visual, and Infrared sensors, and have been analyzed at high speeds to study their effectiveness in detecting and accounting for obstacles and other perception challenges. By creating a common set of testing benchmarks, and by testing in a wide range of real-world conditions, Robotic Research has evaluated where sensors can be successfully employed today, where sensors fall short, and which technologies should be examined and developed further, all to achieve the goal of doubling ground vehicle speeds on any given terrain.

9494-7, Session 2

Multi-model sensor and HMI integration with applications in personal robotics

Rommel A. Alonzo, Sven Cremer, Dan O. Popa, The Univ. of Texas at Arlington (United States)

In recent years, the advancements of object detection, path planning, task-oriented algorithms, and the availability and cost reduction of sensors, have opened the doors to the creation of autonomous robots deployed to assist humans. A personal robot's main task is to provide assistance to humans when requested. However, most robotic platforms are programmed in a generic fashion, and cannot adapt to specific users level of skill and preference. On the other hand, most users expect a personalized level of uniqueness from their other electronic devices. We aim to introduce this level of uniqueness into the world of robotics.

This paper proposes a multi-modal robotic framework where a platform and its sensors autonomously recognizes a user and reconfigures its level of access and operation to suit that user. Multiple forms of HMI's (Human-Machine Interface) are presented and a software architecture is formed that can adjust the type of task that it was previously configure to present. Multiple forms of sensor fusion with range, pressure, and odometry sensors are used to recognize human intent. Experimental results with a Qinetiq DragonRunner Robot are tested on multiple users to examine the robots ability to adapt to its environment and to its user.

9494-8, Session 2

Robotic situational awareness of actions in human teaming

David Tahmoush, U.S. Army Research Lab. (United States)

When robots can sense and interpret the activities of the people they are working with, they become more of a team member and less of just a piece of equipment. This has motivated work on recognizing human actions using existing robotic sensors like short-range ladar imagers. These produce three-dimensional point cloud movies which can be analyzed for structure and motion information. We skeletonize the human point cloud and apply a physics-based velocity correlation scheme to the resulting joint motions. The twenty actions are then recognized using a nearest-neighbors classifier that utilizes a similarity threshold to achieve high accuracy.

9494-9, Session 2

Performance evaluation and clinical applications of 3D plenoptic cameras

Ryan Decker, Azad Shademan, Justin Opfermann, Simon Leonard, Peter C. W. Kim, Axel Krieger, Children's National Medical Ctr. (United States)

Viewers experience visual discomfort, such as eyestrain and associated symptoms including nausea and headaches, often enough to present a barrier to the popularization of stereoscopic 3D technology. Even though various researches have examined the factors that cause visual discomfort in watching 3D stereoscopic video, the brigthness factor was not well dealt with. In this paper, we analyze visual discomfort under various illumination conditions by considering eye-blinking and saccadic movements. In addition, we measured the perceived depth before and after watching 3D stereoscopic video using our own 3D depth measurement instrument.

Our test sequences consist of 6 illumination conditions each for foreground and background only. The Illumination is changed from bright to dark or in inverse direction. Our test procedure is as follows: First, the subjects get rested until they were certain to have no visual discomfort. Then, the subjects answered eight questions to check their subjective pre-stimulus discomfort. Next, the participant watched the 30-minute stereoscopic 3D and 2D video clips in random order. We measured eye-blinking, saccadic movements and fixation of the participant using an eye-tracking device. Finally, we measured perceived depth for each subject before and after watching video. We also measured the perceived depth after subjects' taking 40-minute rest to measure the recoverability. Eye-blinking showed a higher score but saccadic movement showed a lower score when watching bright video than dark video. After 40 minutes, most subjects returned to the normal condition in depth perception.

9494-10, Session 2

Surface EMG and Intra-socket Force Measurement to Control a Prosthetic Device

Joe D. Sanford, The Univ. of Texas at Arlington (United States); Rita M. Patterson, Univ. of North Texas Health Science Ctr. at Fort Worth (United States); Dan O. Popa, The Univ. of Texas at Arlington (United States)

Surface electromyography (SEMG) has been shown to be a robust and reliable interaction method allowing for basic control of powered prosthetic devices. Commercially available dexterous devices are available with increasing numbers of degrees of freedom over past systems. Users of these devices with the most severe levels of amputation require the most complex devices with the greatest number of degrees of freedom. However, the smaller the remainder limb due to an increase in amputation severity, the fewer viable SEMG sites are available as control inputs. This inverse issue, controlling complex dexterous devices with limited available inputs, requires the addition of sensing and interaction modalities. Research has shown a marked decrease in EMG-classification efficiency throughout activities of daily life due to socket shift and movement as well as changes in degree of fit of the socket throughout the subject's lifetime. Previous work, which reported the use of intra-socket pressure as measured during flexion and extension of a subject's carpi flexor and extensor muscles, has shown that it is possible to control a powered prosthetic device. In this paper, we present data correlating SEMG data with intra-socket pressure data. Surface EMG sensors and force sensors were housed within a prosthetic cuff fit to a healthy-limbed subject. EMG and intra-socket force data was collected from inside the cuff as the subject performed pre-defined grip motions with their dominant hand. Data fusion algorithms were explored and allowed a subject to use both intra-socket pressure and SEMG data as control inputs for a powered prosthetic device. This additional input modality allows for an improvement in input classification as well as information regarding socket fit through out activities of daily life.

9494-11, Session 2

Resolving ranges of layered objects using ground vehicle LiDAR

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Lidar systems are well known for their ability to measure three-dimensional aspects of a scene. This attribute of Lidar has been widely exploited by the robotics community, among others. The problem of resolving ranges of layered objects (such as a tree canopy over the forest floor) has been studied from the perspective of airborne systems. However, little research exists in studying this problem from a ground vehicle system (e.g., a bush covering a rock or other hazard). This paper will discuss the issues involved in solving this problem from a ground vehicle. This will include analysis of extracting multiple-return data from Lidar and the various laser properties that impact the ability to resolve multiple returns, such as pulse length and beam size. The impacts of these properties are presented as they apply to three different Lidar imaging technologies: Scanning Pulse Lidar, Geiger Mode Flash Lidar, and Time-of-Flight camera. Tradeoffs associated with these impacts are then discussed for a ground vehicle Lidar application.

9494-25, Session 2

Untethered microscale flight: mechanisms and platforms for future MEMS aerial microrobotics

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This paper describes initial work demonstrating untetherd microscale flying structures as a platform for new class of aerial microrobots. We present and analyze both bio-mimetic structures based partially on wing designs of smallest flying insects on Earth, as well as stress-engineered structures powered by radiometric (thermal) forces. The latter devices, also called MEMS Microfliers are 300 μm x 300 μm x 1.5 μm in size, and are fabricated out of polycrystalline silicon. A convex chassis, formed through a novel in-situ masked post-release stress-engineering process, ensures their static in-flight stability. High-speed optical micrography was used to image these MEMS Microfliers mid-flight.

9494-28, Session 2

Towards energy harvesting system for mesoscale intra-body robot power

Kanty Rabenorosoa, Micky Rakotondrabe, FEMTO-ST (France)

Mesoscale robots and active capsules are clearly identified as future trends of medical robots thanks to their dimension more suitable for minimal invasive intervention. Among the applications of mesorobots which are essentially capsules, we find: imaging of gastrointestinal tract, biopsy. The most success of passive capsules are achieved for monitoring or video

acquisition inside a small bowel or GI tract. As passive capsules were limited in terms of task accomplishment, the development of active capsules has been increasing. The main limitation of active capsules, however, is the limited power and autonomy of the embedded energy used both for locomotion and for task accomplishment despite of the multipurpose robotic abilities. This energy limitation is particularly due to the limited volume of the capsule and thus a weak accumulated energy. This paper propose a system for energy harvesting for capsules. Based on external oscillating magnetic actuation and piezoelectric structure, the proposed approach can be used to power autonomous mesorobots for locomotion and for tasks accomplishments. The design of the system is first described afterwards the modeling of the magnetic excitation is discussed. The piezoelectric system is presented and simulation results are presented. A prototype is tested to prove the feasibility of the concept.

9494-12, Session 3

Automated actuation of multiple bubble microrobots using computer-generated holograms

M. Arifur Rahman, Julian Cheng, Qihui Fan, Aaron T Ohta, Univ. of Hawaii at Manoa (United States)

Microrobots, defined here as sub-millimeter untethered microactuators, have applications in micro-object manipulation, including cellular manipulation, microsurgery, microassembly, tissue culture, and drug delivery. Laser-induced opto-thermocapillary flow-addressed bubble (OFB) microrobots are promising tools for the transportation of micro-objects. In the OFB microrobot system, laser patterns generate thermal gradients within a liquid media, forming thermocapillary forces that actuate the bubble microrobots. An automated control system is being developed using a spatial light modulator (SLM), with the goal of independently addressing 50 OFB microrobots. The SLM was controlled using computer generated hologram to create an optical pattern consisting of 50 individual spots. The OFB microrobots were independently controlled using gray-level holographic patterns. Each array of microrobots corresponds to a specific computer generated hologram (CGH), so a sequence of CGHs can be used to achieve the desired navigation of microrobots. Using the CGH control system, single, multiple, and groups of microrobots were created, repositioned, and maneuvered independently within a set workspace. Compared to the other actuation methods such as optically induced dielectrophoresis (ODEP), optical tweezers, electrostatic force, and magnetic force, the CGH-controlled microrobot system is not as reliant on the properties or chemistry of the target object. Moreover, this OFB microrobotic system does not require extensive fabrication, and increases the throughput compared to other microrobotic systems.

9494-13, Session 3

An ontology to enable optimized task partitioning in human-robot collaboration for warehouse kitting operations

Ashis G. Banerjee, Andrew Barnes, GE Global Research (United States); Krishnanand N. Kaipa, Jiashun Liu, Shaurya Shriyam, Nadir Shah, Satyandra K. Gupta, Univ. of Maryland, College Park (United States)

Collaborative teams of human operators and mobile ground robots are becoming popular in manufacturing plants to enhance the overall productivity by having robots assist humans with a lot of the repetitive tasks. An example of such a task category is the packing of individually separate but related objects into different units, an operation known as kitting. This operation is essential for effective inventory management in assembly warehouses. Kitting poses several research challenges, one of which is the effective partitioning of the operation tasks between humans and robots so as to minimize the expected operation time. To address this challenge, we develop an ontology to provide a unified representation of all kitting-related tasks, which are decomposed into atomic actions that are either computational, involving sensing, perception, planning, control, and learning, or physical, involving actuation and manipulation. The ontology is based on a stochastic model of robotic object grasping where the object poses are estimated by extracting edges from the corresponding camera images of the objects and performing template matching with the object CAD models. A stochastic integer linear program then uses this ontology to perform task partitioning between the robots and humans. Preliminary experiments on a single robot - single human case, involving picking and placing of different industrial parts, yield promising results. The task partitioning involves the robot seeking human assistance for visual perception tasks while performing the other tasks on its own. The operations are completed with higher success rates and lower completion times using human-robot partnership versus just the human or only the robot.

9494-14, Session 3

Control of a Powered Prosthetic Device via a Pinch Gesture Interface

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Pinch gesture based user input systems have been demonstrated in Virtual Environments [Zeleznik et al.]. Wrist-worn, gloveless hand gesture tracking systems also exist [Kim et al.]

We present a novel system to control a powered prosthetic device (the TouchBionics RoboLimb) using a gesture tracking system worn on the sound hand in order to select different grasp patterns. We have created a gesture tracking system comprised of conductive thimbles worn on each finger to control the RoboLimb device.

We have performed timing tests on the selection and execution of three grasp patterns using 1) Our gesture system 2) The iPhone app provided by TouchBionics 3) Using an intra-socket force tracker developed in our group.

Our preliminary results indicate that one of three grasp patterns can be selected and executed within 2.374 (+-0.31) seconds with 100% accuracy (n=25). The user was also able to perform basic object manipulation tasks. When used with our intra-socket pressure based system, the gesture took (5.098+- 1.51) seconds on average.

We believe a low encumbrance gesture based wearable system for selecting grasp patterns may provide a viable alternative to EMG and other prosthetic control modalities.

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9494-15, Session 3

Interaction models between robots wearing sensorized skin and their environment

Md Ahsan Habib, Ioana Corina Bogdan, Dan O. Popa, The Univ. of Texas at Arlington (United States)

In this paper, we present a simulation platform to investigate how design parameters of sensorized skins (such as size and pitch) affect

the performance of human-robot interaction. Here the task considered is a controlled interaction between a robot surface equipped with tactile sensors and an external environment. A PI controller is bused to execute force-based explicit force control based on tactile feedback in order to exert a desired force onto the environment. The performance criteria of the task considered are rise time, settling time, steady-state force error, and center of pressure estimate. Generalization of design conclusions from the simulation environment to real robot skin requires accurate modeling of contact between interacting bodies, reliable transfer of contact force to the tactile sensor and accurate simulation models for tactile sensors. In [1,2], a reduced-order model was proposed to relate the force applied to robot skin to the force sensed by the embedded tactile sensor. In this report, further modeling aspects of tactile skin systems are discussed, such as array modeling, data management, pressure distribution models through compliant sensor cover materials with varying thicknesses and the modeling of noise involved in the sensor system. We present how these models were implemented on SkinSim, our software testbed environment[3].

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[2] A. Habib et al., SkinSim: A Simulation Environment for Multimodal Robot Skin. CASE 2014.

[3] SkinSim, https://bitbucket.org/nextgensystems/skinsim

9494-27, Session 3

Multi-mode vibration suppression in MIMO systems using zero placement input shaping technique

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Piezoelectric cantilever structured actuators are well appreciated for the development of high precision and high dynamics positioning systems (micropositioners) thanks to their high bandwidth, high resolution and ease of powering (electrical). However these piezoelectric micropositioners exhibit badly damped vibrations due to the cantilever structures. These behaviors strongly affect the final performances, or even the stability, of the tasks to be executed.

The increasing need on dexterous actuated systems led to the development of piezoelectric micropositioners with multiple degrees of freedom (for instance [1-4]). In [5], a 2-DOF piezoelectric micropositioner principle was patented. It is capable to perform microrobotic tasks such as micromanipulation with submicrometric resolution and along two axes [6,7], see Fig.1. Nonetheless this micropositioner exhibits badly damped vibrations not only in the direct transfers but also in the cross-couplings transfers.

This paper deals with the feedforward control of the vibrations for the 2-DOF piezoelectric micropositioner in order to damp the vibrations in the direct axes and to reduce the cross-couplings. The novelty in this paper relative to the existing vibrations feedforward control, i.e. control without sensors, in piezoelectric systems [8-10] is the account for the strong cross-couplings. For that, we propose to extend the zero placement input shaping technique [11] to account for the direct transfers as well as the cross-couplings and to have more robustness relative to model uncertainties. Experimental tests on the 2-DOF piezoelectric micropositioner have been carried out and demonstrate the efficiency of the proposed method.

9494-29, Session 3

Simultaneous suppression of badly-damped vibrations and cross-couplings in a 2-DoF piezoelectric actuator, by using feedforward standard H∞ approach

Didace Habineza, Micky Rakotondrabe, Yann Le Gorrec, FEMTO-ST (France)

Multi-axis piezoelectric actuators are very known in spatial positioning tasks, especially in micro/nano scale applications. However, the positioning precision of these actuators and the stability of the final tasks are compromised by badly-damped vibrations and by the cross-couplings between actuators axis. In the litterature, inverse-dynamics [3] and input-shaping [1,4] techniques rank among the most used techniques for feedforward control of vibrations. However, the identification of the multi-axis piezoelectric actuators, such as piezoelectric tube scanners, may lead to nonminimum-phase and non-bicausal models, for which the inverse-dynamics control approaches require are not necessarily utilizable [9]. In this paper, we propose a feedforward H∞ approach to control a 2-axis piezoelectric actuator. This leads to a bivariable compensator, able to suppress the vibrations in the direct transfers and able to reduce the amplitudes of the cross-couplings. The proposed approach allows to calculate a feedforward vibrations compensator without any need to invert the model, which is an easier and less time-consuming way than with inverse-dynamics based techniques. Furthemore, the calculated compensator is also easier to implement comparably to classical input-shaping compensators. The experimentations carried out demonstrate the efficiency of the proposed approach.

Conference 9494B: Machine Intelligence and Bio-inspired Computation: Theory and Applications IX

Tuesday 21–21 April 2015

Part of Proceedings of SPIE Vol. 9494 Next-Generation Robotics II; and Machine Intelligence and Bio-inspired Computation: Theory and Applications IX

9494-16, Session 1

Evolving spiking neural networks: a novel growth algorithm exhibits unintelligent design

J. David Schaffer, Binghamton Univ. (United States)

Spiking neural networks (SNNs) have drawn considerable excitement because of their computational properties, believed to be superior to conventional von Neumann machines, and sharing properties with living brains. Yet progress building these systems has been limited because we lack a design methodology. We present a gene-driven network growth algorithm that enables a genetic algorithm (evolutionary computation) to generate and test SNNs. The genome for this algorithm grows O(n) where n is the number of neurons; n is also evolved. The genome not only specifies the network topology, but all its parameters as well. Experiments show the algorithm producing SNNs that effectively produce a robust spike bursting behavior given tonic inputs, an application suitable for central pattern generators. Even though evolution did not include perturbations of the input spike trains, the evolved networks showed remarkable robustness to such perturbations. In addition, the output spike patterns retain evidence of the specific perturbation of the inputs, a feature that could be exploited by network additions that could use this information for refined decision making if required. On a second task, a sequence detector, a discriminating design was found that might be an example of "unintelligent design", extra non-functional neurons were included that did not hamper its proper functioning.

9494-17, Session 1

Experimental analysis of a Lotka-Volterra neural network for classification

Christopher L. Sukhu, Joseph E. Stanton, Marc Aylesworth, BAE Systems (United States)

An experimental study of a neural network modeled by an adaptive Lotka-Volterra system follows. With totally inhibitory connections, this system can be embedded in a simple classification network. This network is able to classify and monitor its inputs in a spontaneous nonlinear fashion without prior training. We describe a framework for leveraging this behavior through an example involving breast cancer diagnosis.

9494-18, Session 1

Collaborative mining and transfer learning for relational data

Georgiy M. Levchuk, Andres Ortiz, Aptima, Inc. (United States)

Numerous automated data analysis algorithms have been developed in the last decade to learn patterns from training data. However, current state of the art solutions are not suitable for anti-access areas of denial (A2AD) domain, where the communication is limited, data is distributed, and computation resources are not reliable. Moreover, most of the real-world data mining involves "relational" data, where the links between individual data variables and values are diverse and carry essential contextual information. Only limited research on transfer learning for relational data has been conducted, with the most prominent work using Markov Logic Networks to transfer relational information (Davis and Domingos, 2009; Mihalkova, and Mooney, 2009). These models only allow transferring the knowledge from one resource to the next, and are not suitable for collaborative learning applications.

In this paper, we present a model that combines the benefits of transfer learning over relational (graph) data with capabilities provided by collaborative learning approaches. In our model, a group of distributed resources has access to potentially overlapping relational data subsets. Over time, the resources incrementally process available information, form the patterns representing their view of the world, and update those patterns by exchanging influencing and knowledge transfer messages. This model allows the resources to learn the same, similar, and different but interdependent tasks in a single conceptual framework. The algorithms presented in this paper build a foundation for the greater autonomy for data mining applications. As a validation, we present the experimental results using TREC KBA dataset.

9494-19, Session 1

Spike encoding for dynamical control system architecture

Bryant T. Wysocki, Thomas A. McEwen, Clare D. Thiem, Nathan R. McDonald, Air Force Research Lab. (United States)

The concept of reservoir computing is being examined as a means to develop a dynamical control system architecture for Air Force applications. Reservoir computing is a bio-inspired approach to computation with methodologies based on machine learning that provides methods of design, training, and testing of recurrent neural networks (RNN) and dynamical neural processors. Key to this research is figuring out the fundamental aspects of data representation using hardware-based spike-timing-dependent encoding for processing in neuromorphic architectures. Time encoding efficiently maps a signal's amplitude information into a spike time sequence that represents the input data and offers perfect recovery for band-limited stimuli. Understanding how sensory information is represented in neuronal activity is central for perception and is a crucial aspect of artificially intelligent cortical systems. Using a combination of modeling, simulation, and bench top experimentation, Air Force researchers are beginning to explore the trade space for creating practical reservoir computing technology. An initial spike encoding circuit has been designed and prototyped for lab bench experimentation. Motivation for this research, accomplishments to date and a plan for the way forward will be presented in this paper. Successful completion of this work will set the stage for a new level of neuromorphic computing for the control of complex Air Force systems.

9494-20, Session 2

Experimental study of a fuzzy-logic-based control approach for maintaining wireless communication connections among multiple mobile robots

Xu Zhong, Stony Brook Univ. (United States); Yu Zhou, State Univ. of New York Institute of Technology (United States)

This paper addresses the fundamental and challenging problem of forming

and maintaining wireless communication connections among multiple collaborative mobile robots in physical environments. Adapting to the instability and uncertainty of wireless signal propagation in reality, a fuzzy-logic based decentralized control approach is proposed for deploying a team of collaborative mobile robots into an unknown environment while maintaining the desired wireless link quality among the robots. Each robot is controlled by an onboard fuzzy controller: a set of membership functions and fuzzy rules are defined for each robot to map the wireless link quality with a neighbor to its communication-maintaining movement relative to the neighbor; the control decision of a robot with multiple neighbors is made by aggregating the decisions for dealing with all its neighbors. The combined effect of all the robots' movement leads to the desired communication connectivity among the robots. To validate the proposed control approach, an experimental study has been carried out. The experimental system consists of a team of physical mobile robots, each of which is equipped with the onboard modules and algorithms of motion control, wireless communications and localization. In particular, ZigBee modules are utilized to wirelessly communicate the control-related information and to detect the wireless link quality among the robots. The parameters of the fuzzy controller are iteratively adjusted to attain appropriate control outputs in response to the positions and wireless link quality of neighbors. The tuned fuzzy controller is used to control the robots to maintain desired wireless communication connections. The experimental results are reported, which show that the proposed control approach is able to guide the whole multi-robot system to converge to the desired connectivity while forming a coverage across the environment.

9494-21, Session 2

Bio-inspired approach for intelligent unattended ground sensors

Nicolas Hueber, Pierre Raymond, Christophe Hennequin, Maxime Perrot, Alexander Pichler, Philippe Voisin, Julien Pichard, Jean-Pierre Moeglin, Institut Franco-Allemand de Recherches de Saint-Louis (France)

New conflict areas and terrorism are changing the way military strategies are operated. Small groups spread terror over huge areas which are difficult to survey 24/7, even with UAVs and a satellite constellation. This research project aims at improving the surveillance capacity over such wide zones in order to increase the safety of civilians, troops and infrastructures. In this context, global sensing and situational awareness require a set of smart battery-powered UGS (Unattended Ground Sensors) capable of issuing an alarm to a decision-making center. Only high-level information is sent, when a relevant suspicious situation occurs.

This paper proposes an innovative bio-inspired approach that mimics the human bimodal vision mechanism and the parallel processing ability of the human brain. Our prototype exploits two levels of analysis: a low-level panoramic motion analysis called peripheral vision, and a high-level event-focused analysis: foveal vision. By tracking moving objects and fusing multiple criteria (size, speed, trajectory, etc.), the peripheral vision module acts as a fast relevant event detector. The foveal vision module focuses on this detected event to extract more detailed features (texture, color, shape, etc.) for the recognition core. Our bio-inspired recognition process is able to acquire human knowledge and to classify in real time a huge amount of heterogeneous data thanks to its natively parallel structure.

The bio-inspired prototype demonstrates, under laboratory tests, a low false alarm rate. By locally processing the data and sending only high-level information, its energy requirements and electromagnetic signature are optimized. Moreover, the embedded Artificial Intelligence core enables this unique smart sensor to recognize and learn new significant events.

These results are paving the way for future reconfigurable virtual field agents. By duplicating human expertise in potentially hazardous places, our miniature visual event detector will allow early warning and contribute to better human decision making.

9494-22, Session 2

Evaluating data distribution and drift vulnerabilities of machine learning algorithms in secure and adversarial environments part two

Kevin M. Nelson, George E. Corbin, Mark Anania, Matthew G. Kovacs, BAE Systems (United States); Misty Blowers, Air Force Research Lab. (United States)

Machine learning is rapidly emerging as a valuable technology thanks to its ability to learn patterns from large data sets and solve problems that are impossible to model using conventional programming logic. As machine learning techniques become more mainstream, they are being applied to a wider range of application domains. These algorithms are now trusted to make critical decisions in secure and adversarial environments such as healthcare, fraud detection, and network security, in which mistakes can be incredibly costly. However, machine learning's data-driven approach, while normally one of its greatest benefits, can also prove to be a weakness if the data on which the models rely are corrupted by an adversary. Models that utilize on-line learning or are periodically retrained to learn new patterns and account for drift and data distribution changes are particularly susceptible to "poisoning attacks." In this class of attack, specially crafted data points are added to the training set to maliciously influence the system by inducing adversarial drift which leads to incorrect classifications. 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 susceptibility of several anomaly detection algorithms to adversarial drift as well as the effects of a poisoning attack against intrusion detection systems which rely on these methods.

9494-23, Session 3

Subset selection of training data for machine learning: a situational awareness system case study

Mark C. McKenzie, Sebastien Wong, Defence Science and Technology Organisation (Australia)

Recent advances in machine learning with big data sets has allowed for significant advances in the optimisation of classification and recognition systems. However, for applications such as situational awareness systems, the entirety of the available data dwarfs the amount permissible for a training set with tractable machine learning optimization times. Furthermore, the performance of any optimized system is highly dependent of the training set correctly and completely representing the entire data space of scenarios. In this paper we present a technique to characterize the entire data space to ascertain the key factors for representation and subsequently select a subset that statistically represents the correct mix of scenarios. We demonstrate the effectiveness of these characterization and subset selection techniques by using a genetic algorithm to optimize the performance of a gunfire recognition system.

9494-24, Session 3

Realistic computer network simulation for network intrusion detection dataset generation

Garrett S. Payer, ICF International (United States)

The KDD-99 Cup dataset is dead. While it can be continued to be used as a toy example, the age of this dataset makes it all but useless in the area of intrusion detection research and data mining. Many of the attacks used within the dataset are obsolete and do not reflect the features important for intrusion detection in today's networks.

Creating a new dataset encompassing a large cross section of the attacks found on the Internet today could be useful, but would eventually fall to the same problem as the KDD-99 Cup; its usefulness would diminish after a period of time. Worse, the rate of decline in usefulness would occur at a much faster rate than that of the KDD-99 Cup as today's attackers are much more sophisticated, switching attack vectors and methodology on almost a daily basis.

In order to continue research into intrusion detection, generation of datasets needs to be as dynamic and as quick as the attacker. Simply examining existing network traffic and using domain experts such as intrusion analysts to label traffic is inefficient, expensive, and not scalable. The only viable methodology to is to produce this information via simulation using a combination of technologies including virtualization, attack tool sets such as Metasploit and Armitage, and sophisticated emulation of threat and user behavior.

By simulating actual user behavior and network intrusion events dynamically not only allows researchers to vary scenarios quickly, but allows online testing of intrusion detection mechanisms by interacting with data as it's generated. As new threat behaviors are identified, they can be added to the simulation to make quicker determinations as to the effectiveness of existing and ongoing network intrusion technology, methodology and models. Additionally, the dataset generated by the experiments as well as it's configuration can be distributed with the associated research to facilitate additional verification and additional research.

9494-25, Session 3

Change detection in satellite imagery using clustering of sparse approximations (CoSA) over learned feature dictionaries

Daniela I. Moody, Los Alamos National Lab. (United States)

Neuromimetic machine vision and pattern recognition algorithms are of great interest for landscape characterization and change detection in satellite imagery in support of global climate change science and modeling. We present results from an ongoing effort to extend machine vision methods to the environmental sciences, using adaptive sparse signal processing combined with machine learning. A Hebbian learning rule is used to build multispectral, multiresolution dictionaries from regional satellite normalized band difference index data. Land cover labels are automatically generated via our CoSA algorithm: Clustering of Sparse Approximations, using a clustering distance metric that combines spectral and spatial textural characteristics to help separate geologic, vegetative, and hydrologic features. Land cover labels are estimated in example Worldview satellite images of a particular region taken at different times, and are used to detect seasonal and yearly surface changes. Our results suggest that neuroscience-based models are a promising approach to practical pattern recognition problems in remote sensing.

Conference 9495: Three-Dimensional Imaging, Visualization, and Display 2015

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9495-1, Session 1

Portable digital holographic microscope using spherical reference beam and its biomedical applications *(Invited Paper)*

Eriko Watanabe, Kanami Ikeda, Kazuhiro Hoshino, The Univ. of Electro-Communications (Japan)

Digital holographic microscopy has significant potential for use in medicine because it is a noninvasive and nondestructive quantitative phase measurement technique for imaging transparent microscopic objects. For instance, regenerative therapy for treating ocular surface disease is highly attractive, and noninvasive, nondestructive, and nonstaining evaluation techniques are necessary for characterizing these ocular cells so that the therapy can be standardized and made suitable for widespread use.

In this study, we introduce a portable digital holographic microscope (DHM) that achieves microscopic phase imaging with a high resolution over large areas with reduced computational load for phase reconstruction. The portable DHM has dimensions of 150 (Width) x 470 (Depth) x 244.5 (Height) mm3, and its integrated charge-coupled device camera and beam splitter result in a simplified alignment along with compactness. The cut-off frequency, which is the highest measurable spatial frequency in this DHM system, was evaluated as the benchmark for spatial resolution, and a value of 575 line pairs/mm was experimentally obtained, which is similar to the theoretical cut-off frequency of 588 line pairs/mm. We also present a new autofocusing technique that utilizes the complex amplitude distribution of transparent phase objects in the DHM system. The efficacy of the technique for performing high-accuracy phase measurements in a wide field of view by dividing the mapping focal length into sections was demonstrated using sheets of epithelial cells.

9495-2, Session 1

Three-dimensional microscopy through liquid-lens axial scanning *(Invited Paper)*

Ana Isabel Doblas-Exposito, Emilio Sánchez-Ortiga, Genaro Saavedra, Univ. de València (Spain); Jorge Sola-Pikabea, Univ de València (Spain); Manuel Martínez-Corral, Univ. de València (Spain); Po-Yuan Hsieh, Yi-Pai Huang, National Chiao Tung Univ. (Taiwan)

n this contribution we analyze the feature of two different type of electrically-addressable lenses for rapid axial scanning in three-dimensional wide-field microscopy. We have found that liquid-crystal lenses are still slow and microscopy images show significant aberrations. However, fast improvement of this technology permits to predict the utility of these elements in short term. Currently, liquid lenses provide fast axial scanned images with invariant magnification and resolution. We illustrate our research with some microscopy experiments.

9495-3, Session 1

An integral imaging augmented reality display *(Invited Paper)*

Hong Hua, College of Optical Sciences, The Univ. of Arizona (United States); Bahram Javidi, Univ. of Connecticut (United States)

In this presentation, we will review the recent advancements in true 3D wearable AR displays and present a new approach to the design of an optical see-through head-mounted display for augmented reality applications, which combines the recent advancement of freeform optical technology and microscopic integral imaging (micro-InI) method. A micro-InI unit creates a 3D image source for HMD viewing optics, instead of a typical 2D display surface, by reconstructing a miniature 3D scene from a large number of perspective images of the scene. By taking advantage of the emerging freeform optical technology, our approach will result in compact, lightweight, goggle-style AR display that is potentially less vulnerable to the accommodation-convergence discrepancy problem and visual fatigue. A proof-of-concept prototype system will be demonstrated, which offers a goggle-like compact form factor, non-obstructive see-through field of view, and true 3D virtual display.

9495-4, Session 1

Integrated fluorescence and phase-contrast digital holographic microscopy for live cell imaging

Xiangyu Quan, Kouichi Nitta, Osamu Matoba, Kobe Univ. (Japan); Peng Xia, Yasuhiro Awatsuji, Kyoto Institute of Technology (Japan)

Fluorescent stained imaging and phase contrast imaging are the most commonly use methods in biological field. The formal one is suitable of detecting specific parts inside of the cells, while latter is for imaging morphological features of the cells. In many cases, the two methods are inseparable and mutually assisting with each other. Despite the structure differences between the two methods, researches on microscopy that is consisting of the two methods and imaging them simultaneously are developing worldwide. In our study of an integrated fluorescence and phase-contrast digital holographic microscopy system, the three dimensional phase contrast images can be measured as well as a fluorescence image from a single shot exposure.

In the presented method, the phase images are obtained by an off-axis digital holographic microscope with the transmission-type geometry and a fluorescent image is obtained by a fluorescence microscope with the reflection-type geometry. The wavelengths of each illumination are designed to capture simultaneously both the images. For further advancement, fast calculation by means of GPU(graphics process unit) is applied for reconstructing 3D phase images that enables live measurement on cell activities.

The experimental results presented feasibility of simultaneous measurements and it also shows possibilities on important functions as fluorescence digital holography and spectral inspection.

9495-5, Session 2

Floating information display based on aerial imaging by retro-reflection (AIRR) *(Invited Paper)*

Hirotsugu Yamamoto, Utsunomiya Univ. (Japan)

CONTEXT: Floating information display is a display technique that shows information on a transparent, aerial, and floating screen without physical hardware on the screen surface. Floating information display is expected to expand new fields of digital signage and 3D interactions.

OBJECTIVE: This invited paper aims to introduce our floating display technique that utilizes retro-reflection to form aerial image.

METHOD: The proposed display technique, called AIRR (aerial imaging by retro-reflection), employs light sources, a beam splitter, and retro-reflector. Lights are reflected on the beam splitter and then impinge the retro-reflector. After the retro-reflection, the lights travel reversely toward the light sources. About a half of the retro-reflected lights are transmitted through the beam splitter and form real images of the light sources. Thus, aerial images are formed at the symmetrical positions of the light sources with respect to the beam splitter.

RESULTS: We have realized floating LED screen by use of a full-color LED panel, which we originally developed. The full-color LED panel can show full-color images at a high frame rate (960 Hz). Such a high frame rate reduces latency. Floating LED screen is visible over extremely wide viewing angle (90 deg. FWHM). The proposed display technique is utilized for interactive display system called “AIRR Tablet”, http://youtu.be/iJd7fpH8n6M, which is a collaborative work with Prof. Ishikawa at Univ. of Tokyo.

IMPACT: Advantages of AIRR include alignment tolerances, a wide viewing angle, cost-effectiveness of optical components, and forming a real image without stray lights.

9495-6, Session 2

Recent developments in DFD (depth-fused 3D) display and arc 3D display *(Invited Paper)*

Shiro Suyama, Univ. of Tokushima (Japan); Hirotsugu Yamamoto, Utsunomiya Univ. (Japan)

In this paper, we will report recent developments in DFD (Depth-fused 3D) display and arc 3D display, which have smooth movement parallax.

Firstly, DFD display needs only two conventional 2D displays. 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 which has almost linear dependency. DFD image can be protruded outside the region of two planes at about 50% of two plane distance. Moreover, DFD display has small but smooth movement parallax which is important for natural 3D perception and would result in fatigueless and robustness to anisometropia in DFD display.

However, 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. A new method has been proposed to enlarge this DFD image depth. By using low-pass filtered front and rear images, almost linear dependence of perceived depth has been achieved.

Secondly, in arc 3D display, floating 3D images behind or in front of the display can be obtained by lighting the many scratches from upper or lower side. Perceived depth in arc 3D display increases as the arc radius increases and lighting angle decreases whose dependence coincides well with our theoretical calculation. Perceived depth and position are almost the same even when changing observer’s position, resulting in smooth movement parallax.

A new active device has been proposed for switching arc 3D images by using liquid-crystal prism tip. In this device, liquid-crystal region and replica of multi-prism is sandwiched by transparent electrodes. As tangential line of arc-shaped scratches, multi-prism tip of straight line was used to estimate basic operation of high voltage liquid crystal device. Liquid-crystal moves between vertical and inclined direction to glass substrate by applying a high voltage, resulting in change of liquid-crystal refractive index. By this refractive index change, scattering angle at tip of prism can be changed. At the voltage of 1.5 V, scattered light is not observed at the angle of 3D-image observer’s position. When applied voltage increases over 150 V, scattered light is successfully observed at this position. Scattered light angle can be successfully changed by applied voltage change.

The peak brightness of scattered light is also changed by applied voltage. Peak brightness is almost zero under applied voltage of 15 V. Over applied voltage of 75 V, peak brightness increases as applied voltage increases. Our active liquid-crystal device for arc 3D display can be successfully operated as a switchable active device of scattered angle.

Thus, our 3D display methods are promising because of several advantages such as simple structure, smooth movement parallax, etc.

9495-7, Session 2

Floating three-dimensional image display using micro-mirror array imaging element *(Invited Paper)*

Daisuke Miyazaki, Yuki Maeda, Osaka City Univ. (Japan); Satoshi Maekawa, Parity Innovations Co. Ltd. (Japan)

The development of auto-stereoscopic display techniques has recently become active to avoid the use of bothersome 3-D glasses. The achievement of natural depth perception is an important issue for 3-D display technique. In addition, floating image formation is effective to enhance realistic sensation of a 3-D image, and to gain accessibility for direct interactive operation to the image with fingers or 3-D pointing devices.

We have proposed several types of 3-D display systems based on real image formation with optical imaging elements. A volumetric display generates a floating 3-D image by arranging light spots in the air, which satisfies all the criteria of stereoscopy. We have developed several volumetric display systems using two kinds of optical imaging elements, concave mirrors and micro-mirror array devices. A dihedral corner reflector array (DCRA) is a novel a micro-mirror imaging element, which can form a plane-symmetrical real image without image distortions. A real image is moved by an optical scanner to scan a volume.

As another type of an autostereoscopic 3-D display technique, we have been developing floating multi-viewpoint display systems. The multi-viewpoint imaging can be implemented by using multiple projectors or a high-frame-rate single projector and an optical scanner. We used a DCRA device to form a floating real image and images of exit pupils for providing multiple viewpoints. It is possible to expand the viewing area to 360 degrees around a floating image. A multi-view auto-stereoscopic display technique based on the multi-projection method with a DCRA device is proposed. In the proposed display system, a DCRA device forms the real images of the pupils of projectors to provide multiple viewpoints. In addition, a floating image is formed in the air with the DCRA device to avoid vergence-accommodation conflict and to suppress unnatural movement of a floating image accompanied with shifting a viewing position even though the stereoscopic display provides horizontal parallax only. ?

9495-8, Session 3

Evaluation of viewing experiences induced by curved 3D display *(Invited Paper)*

Sungchul Mun, Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of); Sumio Yano, Shimane Univ. (Japan)

As advanced display technology has been developed, much attention has been given to flexible panels. On top of that, with the momentum of the 3D era, stereoscopic 3D technique has been combined with the curved displays. However, despite the increased needs for 3D function in the curved displays, comparisons between curved and flat panel displays with 3D views have rarely been tested. Most of the previous studies have investigated their basic ergonomic aspects such as viewing posture and distance with only 2D views. It has generally been known that curved displays are more effective in enhancing involvement in specific content stories because field of views and distance from the eyes of viewers to both edges of the screen are more natural in the curved display than in the flat panel one. For flat panel displays, ocular torsions may occur when viewers try to move their eyes from the center to the edges of the screen to continuously capture rapidly moving 3D objects. This is due in part to differences in viewing distances from the center of the screen to eyes of viewers and from the edges of the screen to the eyes. In addition, issues in 3D human factors have primarily been explored with either subjective or objective measures rather than their correlations. Thus, this study compares S3D viewing experiences induced by a curved display with those of a flat panel display by evaluating significant subjective and objective measures.

9495-9, Session 3

Accommodation response for integral photography still images

Sumio Yano, Shimane Univ. (Japan); Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of)

The integral photography is representative method in three-dimensional image systems, which are based on the light field reproduction. There are mainly two methods for generation of integral photograph images. One of the generation methods is that the real optical and electrical devices are used; namely, apply the pickup and display equipments. Another method is that integral-photography images are generated using computer software.

In our research, we developed the generation method of integral photography images using computer software. For these integral photography images, we measured the accommodation responses, and analyzed these results. The displayed integral photography images as the visual stimuli were still images. In the experiment, the display size of the integral photography was 4.8 inch; the number of lens was 106 in the horizontal direction and 80 in the vertical direction; the number of elemental images was 18 x 18 dots. The viewing distances were adapted to 60cm and 90cm. For the measurement of accommodation responses, WAM-5500 (SHIGIYA MACHINERY WORKS LTD.) was used. Moreover, the accommodation responses for the real object were also measured for the comparison. We examined the differences of the accommodation responses for the integral photography images and real objects based on measurement results.

9495-10, Session 3

An analysis of brightness as a factor in visual discomfort caused by watching stereoscopic 3D video

Yongwoo Kim, Hang-Bong Kang, The Catholic Univ. of Korea (Korea, Republic of)

Viewers experience visual discomfort, such as eyestrain and associated symptoms including nausea and headaches, often enough to present a barrier to the popularization of stereoscopic 3D technology. Even though various researches have examined the factors that cause visual discomfort in watching 3D stereoscopic video, the brigthness factor was not well dealt with. In this paper, we analyze visual discomfort under various illumination conditions by considering eye-blinking and saccadic movements. In addition, we measured the perceived depth before and after watching 3D stereoscopic video using our own 3D depth measurement instrument.

Our test sequences consist of 6 illumination conditions each for foreground and background only. The Illumination is changed from bright to dark or in inverse direction. Our test procedure is as follows: First, the subjects get rested until they were certain to have no visual discomfort. Then, the subjects answered eight questions to check their subjective pre-stimulus discomfort. Next, the participant watched the 30-minute stereoscopic 3D and 2D video clips in random order. We measured eye-blinking, saccadic movements and fixation of the participant using an eye-tracking device. Finally, we measured perceived depth for each subject before and after watching video. We also measured the perceived depth after subjects' taking 40-minute rest to measure the recoverability. Eye-blinking showed a higher score but saccadic movement showed a lower score when watching bright video than dark video. After 40 minutes, most subjects returned to the normal condition in depth perception.

9495-11, Session 3

The performances of a supermultiview simulator and the presence of monocular depth sense *(Invited Paper)*

Beom-Ryeol Lee, Jeung-Chul Park, Ilkwon Jeong, Electronics and Telecommunications Research Institute (Korea, Republic of); Jung-Young Son, Konyang Univ. (Korea, Republic of)

A supermultiview simulator which can simulate images projected to viewers' eyes at the viewing zone of a 3-D imaging system based on a supermultiview image set. When the image set consists of m different viewing images, the viewing zone of the system is divided into many different regions of viewing individual view images separately and mixed images of 2 to m consecutive view images. The simulator allows each eye of a viewer to perceive two different images which are viewed at different viewing regions. The simulator is intended for investigating the presence of monocular depth sense. The basic optical structure of the simulator has already been introduced to [http://dx.doi.org/10.1117/12.2053234]. The structure is enlarged to display 40inch image at a viewing distance of 1m. The viewing zone of the simulator consists of two viewing regions for left right eyes. The distance between two regions can be adjusted from 54mm to 70mm. This paper will present the performances of the simulator and the presence of the monocular depth obtained with Binocular Accommodation Automatic REF/Keratometer (WAM-5500) [www.grandseiko.com]

9495-12, Session 4

Integral imaging for anti-access/area denial environments *(Invited Paper)*

Shih-Chi K. Chen, Abhijit Mahalanobis, Robert Stanfill, Lockheed Martin Missiles and Fire Control (United States); Bahram Javidi, Univ. of Connecticut (United States)

There is a growing interest in target detection and tracking in Anti-Access/Area Denial (A2AD) environments, where sensor platforms are at low altitudes and imagery are collected at oblique angles. Targets that are of interest in these scenarios are typically partially or mostly occluded by foliage or other objects. We present experiments to illustrate reconstruction of obscured targets using Integral Imaging, in both synthetically generated data and data collected using a multi-sensor system. We also explore the effects of Integral Imaging on Aided Target Recognition (AiTR), as well as performance improvement on target tracking.

9495-13, Session 4

Full-parallax 3D display from single-shot Kinect capture

Seok-Min Hong, Dongseo Univ. (Korea, Republic of); Adrián Dorado, Genaro Saavedra, Manuel Martínez-Corral, Univ. de València (Spain); Dong-Hak Shin, Byung-Gook Lee, Dongseo Univ. (Korea, Republic of)

We propose the fusion between two concepts that very successful in the area of 3D im-aging and sensing. Kinect technology permits the registration, in real time, but with low resolution, of accurate depth maps of big, opaque, diffusing 3D scenes. Our software transform the sampled depth map into an array microimages whose position, pitch and resolution are in good accordance with characteristics of an integral-imaging monitor. Finally we project this information onto the monitor, so that the microlenses integrate the light emitted by the pixels, producing 3D scenes displayed with continuous perspec-tive and full parallax.

9495-14, Session 4

2D MEMS scanning for lidar with sub-Nyquist sampling, electronics and measurement procedure

Thorsten Giese, Joachim Janes, Fraunhofer-Institut für Siliziumtechnologie (Germany)

Electrostatic driven 2D MEMS scanners resonantly oscillate in both axes leading to Lissajous trajectories of a digitally modulated Laser beam reflected from the micro mirror. A solid angle of about 0.02 is scanned by a 658nm Laser beam with a maximum repetition rate of 350MHz digital pulses. Reflected light is detected by an APD with a bandwidth of 80MHz. The phase difference between the scanned Laser light and the light reflected from an obstacle is analyzed by sub-Nyquist sampling. The FPGA-based electronics and software for the evaluation of distance and velocity of objects within the scanning range are presented. Furthermore, the measures to optimize the Lidar accuracy of about 1mm and the dynamic range of up to 4m are examined. First measurements demonstrating the capability of the system and the evaluation algorithms are discussed.

9495-15, Session 4

Shaping field for 3D deep tissue microscopy

Hyungsik Lim, Jorge Colon, Hunter College (United States)

Information capacity of a (lossless) image-forming system is a conserved property determined by two imaging parameters – the resolution and the field of view (FOV). Adaptive optics improves the former by manipulating the phase, or wavefront, in the pupil plane. Here we describe a homologous approach, namely adaptive field microscopy, which aims to enhance the FOV by controlling the phase, or defocus, in the focal plane. The objective of our development is to improve deep tissue imaging. The useful FOV of depth-resolving laser scanning microscopy, such as confocal and multiphoton microscopy, can be severely limited if the region of interest (ROI) is buried in a thick sample and not perpendicular to the optic axis. In this case, one must acquire many z-scans and reconstruct the entirety of ROI by post-processing, which is not only hazardous to tissue, due to excessive radiation, but also time consuming. We demonstrate the substantial enhancement of effective FOV by dynamic control of the image plane. Specifically, the tilt of the image plane is continuously adjusted in situ to match the oblique orientation of the sample plane within tissue. The utility of adaptive field microscopy is tested for imaging tissue with non-planar morphology. Ocular tissue of small animals was imaged by two-photon excited fluorescence. Our results show that adaptive field microscopy utilized the full FOV. The freedom to adjust the image plane to account for the geometrical variations of sample could be extremely useful for 3D biological imaging. Furthermore, adaptive field microscopy could facilitate rapid surveillance of cellular features within deep tissue while avoiding excessive exposure to radiation, making it suitable for in vivo imaging.

9495-16, Session 4

Spatial-spectral volume holographic microscopy

Yuan Luo, National Taiwan Univ. (Taiwan)

Laser induced fluorescence has been developed for a variety of clinical applications. However, many of the existing biomedical imaging systems typically require scanning in two lateral dimensions as well as depth focusing. Efforts to improve scanning efficiency by optimizing the scanning algorithm or increasing the number of focal points are ongoing. However, these methods can increase system complexity and do not eliminate the need for moving parts. This talk will introduce volume holographic imaging systems to acquire spatial images with spectral selectivity and no scanning in both transverse and longitudinal directions. The imaging modality is based upon multiplexed volume holographic (MVH) gratings acting as spatial-spectral filters used in an optical imaging system. In addition, with proper multiplexed holographic pupil engineering, the MVH systems can obtain multiple depth-resolved phase-contrast imaging in real-time in a single shot. Moreover, the talk will address MVH techniques incorporating other state-of-the-art imaging methods to better manipulate light for imaging in a variety of applications.

9495-17, Session 5

Compact integral three-dimensional imaging device *(Invited Paper)*

Jun Arai, Takayuki Yamashita, Hitoshi Hiura, Masato Miura, Ryohei Funatsu, Tomohiro Nakamura, NHK Japan Broadcasting Corp. (Japan); Eisuke Nakasu, NHK Engineering System, Inc. (Japan)

Compact integral three-dimensional (3D) imaging device has been developed that positions the lens array and image sensor close together. Unlike in the conventional scheme, where a camera lens is used to project the elemental images generated by the lens array onto the image sensor, the developed device combines the lens array and image sensor into one unit and makes no use of a camera lens. This eliminates the resolution deterioration and distortion caused by the use of a camera lens and improves, in principle, the quality of the reconstructed 3D image. Images of objects captured with this device were reconstructed as 3D images by using display equipment consisting of a liquid crystal panel and a lens array. The reconstructed images were found to have appropriate motion parallax.

Also developed was a depth control method using an afocal lens array, which is used by combining it with the compact integral 3D imaging device. In the conventional scheme, a convex lens is used to control the depth position of the 3D image, resulting in depth distortion in the reconstructed 3D image. In contrast, the afocal lens array generates a mirror image of the object without depth distortion, which was confirmed by reconstruction of the 3D images of objects.

9495-18, Session 5

Using perceivable light fields to evaluate the amount of information that autostereoscopic displays need to cast *(Invited Paper)*

Adrian Stern, Ben-Gurion Univ. of the Negev (Israel); Bahram Javidi, Univ. of Connecticut (United States)

Recently we introduced the notion of "perceivable light fields" (PLF) as an efficient tool for the analysis and design of three dimensional (3D) displays. The PLFs are used with a 3D display analysis approach that puts the viewer in the center of the model; first the human visual system requirements are defined through the PLF and then they are back-propagated to the display devices to evaluate its specifications. Here we such an analysis to evaluate the information limits that the 3D display devices needs to generate.

9495-19, Session 5

Integral imaging acquisition and processing for human gesture recognition *(Invited Paper)*

Filiberto Pla, Pedro Latorre Carmona, Eva Salvador-Balaguer, Univ. Jaume I (Spain); Bahram Javidi, Univ. of

Connecticut (United States)

In this paper we present an overview of results corresponding to the application of the integral imaging 3D acquisition technique for the recognition of human gestures. Using an array of cameras and 3D scene reconstruction algorithms we obtain a series of videos formed by frames reconstructed and focused by synthetic aperture techniques at specific depths (those where the gesture appears). A state of art bag of visual words approach is then applied on them as well as on two-dimensional single camera videos obtained from one of the cameras of the array. This set up allows comparing recognition results using the same technique on images generated by the integral imaging techniques and plain 2D video cameras. Our results show that for some of the visual descriptors used, integral imaging provides better results (in terms of accuracy) than the monocular case, due to the properties of focused images generated by the 3D reconstruction. These results encourage us to explore this methodology further and exploit properties of integral imaging that may be useful for human gesture recognition.

9495-20, Session 5

Optical barriers in integral imaging monitors through micro-Köhler illumination *(Invited Paper)*

Manuel Martínez-Corral, Héctor Navarro, Genaro Saavedra, Amparo Pons-Martí, Univ. de València (Spain); Raul Martinez-Cuenca, Univ. Jaume I (Spain); Angel Tolosa, AIDO Instituto Tecnológico de Óptica, Color e Imagen (Spain); Bahram Javidi, Univ. of Connecticut (United States)

Usual problem in 3D integral-imaging monitors is flipping, or pseudo-images, that happens when the microimages are seen from neighbor microlenses. These pseudo-images appear when the light rays coming from each elemental image are not passing through the corresponding microlens, and a set of barriers must be used to avoid this crosstalk. We present a pure optical arrangement based on Köh-ler illumination to generate these barriers. The proposed system does not use addi-tional lenses to project the elemental images, so no optical aberrations are intro-duced. As an added benefit, Köhler illumination provides a higher contrast display.

9495-21, Session 6

Digital holographic measurement for voice recording and reproduction *(Invited Paper)*

Osamu Matoba, Hiroki Inokuchi, Kobe Univ. (Japan); Yasuhiro Awatsuji, Kyoto Institute of Technology (Japan)

Digital holography is applied to record and reproduce the sound field in 3D space. To our best knowledge, the reproduction of the sound wave by optical means is new. We briefly review the method of recording and reproducing the sound wave by a tuning fork and a human voice. In the experiments, we present recording of multiple sound waves. Recording characteristics of the fabricated system are presented. Heterodyne method is also applied to record a sound wave with higher frequency than that of frame rate of the image sensor.

9495-22, Session 6

High-speed parallel phase-shifting digital holography system using special-purpose computer for image reconstruction *(Invited Paper)*

Takashi Kakue, Tomoyoshi Shimobaba, Tomoyoshi Ito, Chiba Univ. (Japan)

We report a high-speed parallel phase-shifting digital holography system using a special-purpose computer for image reconstruction. Parallel phase-shifting digital holography is a technique capable of single-shot phase-shifting interferometry. This technique records multiple phase-shifted holograms required for calculation of phase-shifting interferometry by using space-division multiplexing. This technique requires image-reconstruction process for a huge amount of recorded holograms. In particular, it takes a long time to calculate light propagation based on fast Fourier transform in the process and to obtain a motion picture of a dynamically and fast moving object. Then we designed a special-purpose computer for accelerating the image-reconstruction process of parallel phase-shifting digital holography. We developed a special-purpose computer consisting of VC707 evaluation kit (Xilinx Inc.) which is a field programmable gate array board. We also recorded holograms consisting of 128 ? 128 pixels at a frame rate of 180,000 frames per second by the constructed system. By applying the developed computer to the recorded holograms, we confirmed that the developed computer can accelerate the calculation of image-reconstruction process of parallel phase-shifting digital holography ~50 times faster than CPU.

9495-23, Session 6

Implementation of wireless 3D stereo image capture system and 3D exaggeration algorithm for the region of interest

Woonchul C. Ham, Chul-Gyu Song, Luubaatar Badarch, Kangsan Lee, 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 aslo comments on the GPU hardware and CUDA programming for implementation of 3D exaggeraion algorithm for ROI by adjusting and synthesizing the disparity value of ROI (region of interest) in real time. We adopt nonlinear depth mapping to place emphasis on the center ROI region compared with other surrounding regions

We also try to comments on the pattern of aperture for deblurring of CMOS camera module based on the Kirchhoff diffraction formula. We try to find method to obtain the more deblurred image in case of the distance between CMOS camera lens and object being very short. In general, the distance between camera and object should be more than 6cm to obtain clean image of object in CMOS camera module in a usual cellulal phone. We suggest a new method to obtain clean image within this distance based on aperture mechanism by putting a special aperture mask pattern between CMOS lens mechanism and object and adjusting the size and distance between aperture grids.

Synthesized stereo image is real time monitored on the shutter glass type three-dimensional LCD monitor and disparity values of each segment are analyzed to prove the validness of emphasizing effect of ROI.

9495-24, Session 7

Crosstalks in multiview 3D images *(Invited Paper)*

Jung-Young Son, Konyang Univ. (Korea, Republic of); Beom-Ryeol Lee, Electronics and Telecommunications Research Institute (Korea, Republic of); Min-Chul Park, Thibault Leportier, Korea Institute of Science and Technology (Korea, Republic of)

In the 3-D image, the crosstalk is defined as the interference between neighboring view images. The term has been used to quantify the quality of 3-D images but it doesn't look appropriate for the contact-type multiview 3-D displays. This is because the viewing zones of this type displays are divided into a number of viewing regions having diamond shapes, which are much more than that of the multiview images displayed on the display panel. Furthermore, each region provides an image that is different from those in other regions. The images in most of these viewing regions are the mixtures of at least two neighboring different view images. Since the crosstalk in the stereoscopic images is caused by a small intensity portion of an eye image added to the other eye image. This added portion will get into the other eye simultaneously and cause blur in the other eye image. As a consequence of this blur, the depth sense can be reduced. The crosstalk is quantified as the intensity ratio of left (right) eye image to right (left) eye image added to the left (right) eye image. However, it is expected that this crosstalk will have no meaning if size of the viewing region is smaller than that of viewer's pupil. In this case, the images from surrounding viewing regions of the viewing region will simultaneously get into viewer's each eye with the image on the viewing region. Hence the crosstalk definition used in stereoscopic images cannot be used in multiview images. In this paper, the crosstalk concept in the multiview 3-D displays is redefined and the depth sense with the mixed images is investigated.

9495-25, Session 7

Ligthfield superresolution through turbulence *(Invited Paper)*

Juan M. T. Trujillo-Sevilla, Univ. de La Laguna (Spain); Luis Fernando Rodriguez-Ramos, Instituto de Astrofísica de Canarias (Spain); José Manuel Rodríguez Ramos, Univ. de La Laguna (Spain) and ITB-CIBICAN (Spain)

Plenoptic cameras are gaining popularity thanks to its ability of recording the full lightfield. This is, the full distribution of light rays created by a scene in front of the camera. A conventional camera also records the lightfield, but just a projection of it and not the full lightfield as a plenoptic camera does. This enables to make things that are impossible using a conventional camera, such as, a posteriori refocus, 3D mapping, wavefront phase measurement and perspective shifting with no moving parts in the camera.

There are still many features of plenoptic cameras that has not been explored, for example, the typical main limitation in a plenoptic camera is the loss of resolution since not all pixels in the sensors are used. Plenoptic cameras can also be used as a wavefront sensors since the lightfield relates light rays and its directions, and therefore refraction index changes of the media placed in front of the camera can be measured indirectly by means of angle variations of light rays.

In this work we present a new method to improve the resolution of images captured using plenoptic cameras, when the surrounding media introduces refraction index changes that aberrates the wavefront. A formulation based in Fourier optics is presented as well as results using real data.

9495-26, Session 7

Spectral Analysis of Views Interpolated by Chroma Subpixel Downsampling for 3D Autosteroscopic Displays

Avishai Marson, Adrian Stern, Ben-Gurion Univ. of the Negev (Israel)

One of the main limitation of horizontal parallax autostereoscopic displays is the horizontal resolution loss due the need to repartition the pixels of the display panel among the multiple views. Recently we have shown that this problem can be alleviated by applying a color sub-pixel rendering technique. Interpolated views are generated by downsampling the panel pixels at sub-pixel level, thus increasing the number of views. The method takes advantage of lower acuity of the human eye to chromatic resolution. Here we supply further support of the technique by analyzing the spectra of the subsampled images.

9495-27, Session 8

2D MEMS scanning for lidar with sub-Nyquist sampling, set-up and functionality

Joachim Janes, Thorsten Giese, Fraunhofer-Institut für Siliziumtechnologie (Germany)

2D MEMS scanners are used for e.g. Laser projection purposes or Lidar applications. Electrostatic driven resonant torsion oscillations of both axes of the scanners lead to Lissajous trajectories for a digitally modulated Laser beam reflected from the micro mirror. A solid angle of about 0.02 is scanned by a 658nm Laser beam with a maximum repetition rate of 350MHz 50mW digital pulses. Reflected light is detected by an APD with a bandwidth of 80MHz. The phase difference between the scanned Laser light and the light reflected from an obstacle is analyzed by sub-Nyquist sampling allowing the calculation of its distance and velocity. The experimental set-up of the Lidar system is presented and first measurements demonstrating the capability are discussed.

9495-28, Session 8

FTV standardization for super multiview and free navigation in MPEG *(Invited Paper)*

Masayuki Tanimoto, Nagoya Industrial Science Research Institute (Japan)

FTV (Free-viewpoint Television) is 3DTV with infinite number of views and ranked as the top of visual media. It enables users to view 3D scenes by freely changing the viewpoint. MPEG has been developing FTV standards since 2001. MVC (Multiview Video Coding) is the first phase of FTV, which enables efficient coding of multiview video. 3DV (3D Video) is the second phase of FTV, which enables the efficient coding of multiview video and depth data for multiview displays. Views in between linearly arranged cameras are synthesized from the multiview video and depth data in 3DV. Based on recent development of 3D technology, MPEG has started the third phase of FTV, targeting super multiview and free navigation applications. This new FTV standardization will achieve more flexible camera arrangement, more efficient coding and new functionality. Users can enjoy very realistic 3D viewing and walk-through/fly-through experience of 3D scenes in super multiview and free navigation applications

9495-29, Session 8

Research on steady-state visual evoked potentials in 3D displays *(Invited Paper)*

Yu-Yi Chien, Chia-Ying Lee, Fang-Cheng Lin, Yi-Pai Huang, Li-Wei Ko, Han-Ping D Shieh, National Chiao Tung Univ. (Taiwan)

Brain-computer interfaces (BCIs) are intuitive systems for users to communicate with outer electronic devices. Steady-state visual evoked potential (SSVEP) is one of the common inputs for BCI systems due to its easy detection and high information transfer rates. An advanced interactive platform integrated with LCDs is leading a trend to provide an alternative option not only for the handicapped but also for the public to make our lives more convenient. Many studies of SSVEP-based BCI systems have been done in a 2D environment but less with 3D stimuli. However, 3D displays have potentials in SSVEP-based BCI systems because they can offer vivid images, good quality in presentation, various stimuli, and more entertainment. The purpose of this study was to investigate the effect of two important 3D factors (disparity and crosstalk) on SSVEPs. Twelve participants (2 females) ranging in age between 22 to 28 years old participated in the polarized 3D experiment. The results showed that there is a significant difference (p-value<0.05) between large and small disparity angle, and the signal-to-noise ratios (SNRs) of small disparity angles is higher than those of large disparity angles.

9495-30, Session 8

Reconstruct holographic 3D objects by double phase hologram *(Invited Paper)*

Chih-Hung Ting, National Chiao Tung Univ. (Taiwan); Koki Wakunami, Kenji Yamamoto, National Institute of Information and Communications Technology (Japan); Yi-Pai Huang, National Chiao Tung Univ. (Taiwan)

To develop a 3D display which can show true 3D images is very important and necessary. Holography has potential to achieve that objective because holography actually records and reconstructs the recorded object in space by reconstruction of wavefront. Further, to use computer generated hologram (CGH) can solve the major issue of conventional hologram, the recoding process is quite complicated and needs the real objects. The quality of reconstructed image, however, is not good enough if using only one phase-only spatial light modulator (pSLM), for it can just tune the phase information and cannot modify the amplitude information. Although to use two pSLMs by dual-phase modulation method (DPMM) can adjust the phase and the amplitude information at the same time to enhance the quality of reconstructed image, it is hard to use in practical application because of the extremely high accurate calibration of the two pSLMs. Therefore, double phase hologram (DPH) was proposed to use only one pSLM to adjust the phase and the amplitude information simultaneously through DPMM.

9495-31, Session PTue

Format matching using multiple-planes pseudoscopic-to-orthoscopic conversion for 3D integral imaging display

Xin Shen, Xiao Xiao, Univ. of Connecticut (United States); Manuel Martínez-Corral, Univ. de València (Spain); Bahram Javidi, Univ. of Connecticut (United States)

In this paper, we present a technique to generate an elemental image array to match display devices for three dimensional integral imaging. Experimental results show that our technique can accurately match different display formats and improve the display results.

9495-33, Session PTue

Color image authentication scheme via multispectral photon-counting double random phase encoding

Inkyu Moon, Chosun Univ. (Korea, Republic of)

The combination of photon-counting and double random phase encoding based on binary or monochrome image have showed its robustness for secure image retrieval and verification recently. In this paper, we give an overview of the method for color image authentication with multispectral photon-counting imaging (MPCI) and double random phase encoding (DRPE) techniques. In this scheme, the three types of color samples (Red, Green and Blue color) in Bayer images down-sampled from multispectral RGB color image are encrypted with DRPE, respectively. Then, encrypted image for each channel is photon counted. For color image authentication, the photon-counted encrypted image for each channel is decrypted, respectively and composited into a decrypted Bayer image. Finally, the decrypted Demosaicing image is restored using interpolation methods. Experimental results show that the restored color images from the presented method can be efficiently verified with statistical correlations approach.

9495-34, Session PTue

Parallel reconstruction of multiple depth slice images with focused parts in integral imaging via graphics processing unit

Inkyu Moon, Faliu Yi, Chosun Univ. (Korea, Republic of)

In this paper, we give an overview of the method for simultaneous reconstruction of multiple depth images without off-focus points in integral imaging using a graphics processing unit (GPU). The GPU allows parallel processing with multiple processors for the multiple depth images reconstruction by using a lookup table that contains the shifted values along x and y direction for each elemental image for a given depth range. In this scheme, both multiple slice images reconstruction and off-focused part removal are performed simultaneously, which leads naturally to a computational speed acceleration of 3D integral imaging. We examine and compare the computation time of CPU-based and GPU-based slice image reconstruction with only well-focused parts while varying the number of slice images. The speedup ratio is much higher with the increase of number of reconstructed slice image and resolution of elemental image.

9495-35, Session PTue

Optimizing the diffraction efficiency of LCOS-based holography with anomalous reflection by gradient meta-surface

Chuan Shen, Kaifeng Liu, Sui Wei, Lei Ni, Hao Wang, Anhui Univ. (China)

Meta-surface offers an innovative approach to manipulate light with anomalous capabilities. In this paper, we discuss the possibility of inserting a specially designed gradient meta-surface into the pixel architecture of the liquid crystal on silicon (LCOS) for the purpose of optimizing the diffraction efficiency of LCOS-based holography. The pixels in LCOS with feature size approaching the order of visible light wavelength could provide large diffraction angle, unfortunately, scaling down the pixel size would reduce the efficiency of the first diffraction we desired. The metal-insulator-metal (MIM) structure served as the unit cell of meta-surface consists of three layer, i.e., the subwavelength metal nanobrick with varying geometrical parameter and the continuous metal film separated by the insulator layer. A linear phase gradient is exhibited by the unit cells in each pixel period. When illuminated by a polarized incident light, the MIM structure, where a magnetic resonance is created at a particular frequency, can offer an anomalous reflection with high-efficiency and acts as a flat blazed grating. Finally, the light are supposed be diverted to the desired first diffraction. The properties of potential metal, such as Au, Ag, and Al, served as the plasmonic material and suitable insulator have been studied to configure the MIM structure accurately. Investigations are numerically carried out to observe the effects on the distribution of liquid crystal director with Techwiz Software and to obtain the relative diffraction efficiency by using FDTD software. Compared with the conventional LCOS device, the optimization of the diffraction efficiency has been achieved by our proposed structure.

9495-36, Session PTue

Phase retrieval using iterative Fourier transform and convex optimization algorithm

Zhang Fen, Cheng Hong, Quanbing Zhang, Sui Wei, Anhui Univ. (China)

Phase is an inherent characteristic of any wave field. Statistics show that greater than 25% of the information is encoded in the amplitude term and 75% of the information is in the phase term. The technique of phase retrieval means acquire phase by computation using magnitude measurements and provides data information for holography display, 3D field reconstruction, X-ray crystallography, diffraction imaging, astronomical imaging and many other applications.

Mathematically, solving phase retrieval problem is an inverse problem taking the physical and computation constraints. Some recent algorithms use the principle of compressive sensing, such as PhaseLift, PhaseCut and compressive phase retrieval etc. they formulate phase retrieval problems as one of finding the rank-one solution to a system of linear matrix equations and make the overall algorithm a convex program over matrices. However, by “lifting” a vector problem to a matrix one, these methods lead to a much higher computational cost as a result. Furthermore, they only use intensity measurements but few physical constraints.

In the paper, a new algorithm is proposed that combines above convex optimization me-thods with a well known iterative Fourier transform algorithm (IFTA). The IFTA iterates between the object domain and spectral domain to reinforce the physical information and reaches convergence quickly which has been proved in many applications such as com-pute-generated-hologram (CGH). Herein the output phase of the IFTA is treated as the initial guess of convex optimization methods, and then the reconstructed phase is numerically com-puted by using modified TFOCS. Simulation results show that the combined algorithm increases the likelihood of successful recovery as well as improves the precision of solution.

9495-37, Session PTue

A novel hybrid phase retrieval algorithm for partially coherent light illuminations

Hong Cheng, Fen Zhang, Sui Wei, Yanliu Liu, Yapin Chen, Anhui Univ. (China)

The phase carries details of the depth information about an optical wave field and is very important in many applications, such as optical field reconstruction and 3D display. However, optical waves oscillate too fast for detectors to record the intensity and phase directly and simultaneously. The phase retrieval technology or algorithm has been the focus of enormous research recently.

Among the valuable algorithms transport-of-intensity equation (TIE) and angular-spectrum-iteration (ASI) are widely used in various fields such as electron microscopy and x-ray imaging. Unfortunately, the former one is originally derived for a coherent illumination and can not be directly applied to the phase retrieval of partially coherent light field when not been uniformly lit. While the ASI deducted from wave propagating with wave vector has itself shortcomings due to iterative uncertainty and slow convergence.

In this paper, a novel hybrid phase retrieval algorithm extended TIE for partially coherent light illuminations is investigated in both case of uniformly and non-uniformly lit. This algorithm consists of multi-plane ASI to utilize the physical constraints between the object domain and the spectral domain, and the relationship between the intensity and phase among the wave propagation. The phase at the center image plane is calculated from three intensity images. Then this result is treated as the initial value of the multi-plane ASI. Finally, the phase information at the object plane is acquired according the reversibility of the optical path. This hybrid algorithm expands the application of tradition TIE while improving the convergence rate of ASI method.

9495-38, Session PTue

3D High Speed Characterization Of Phase Objects Using The Transport Of Intensity Equation

Thanh Nguyen, Georges T. Nehmetallah, The Catholic Univ. of America (United States); Ahmad Darudi, Peyman Soltani, Univ. of Zanjan (Iran, Islamic Republic of)

Traditionally, 3D phase information are obtained using interferometric or holographic techniques. While these techniques are very sensitive to vibrations, and vibration cancelation platforms are needed to obtain decent results, non-interferometric intensity based techniques of phase retrieval such as the transport of intensity equation (TIE) do not suffer from such a drawback. TIE employs a simple experimental technique for phase reconstruction of objects by recording several diffraction patterns at different observation planes through axially translating the CCD. Recently, instead of the slow mechanical translation, a Tunable Lens was proposed to modify the TIE setup (TL-TIE) for dynamic phase objects.

In this work we purpose to extend the TL-TIE by employing a tunable lens in the optical setup for phase (transmissive) as well as amplitude (reflective) objects. This modified setup will reduce the acquisition time making the TIE technique useful for dynamic object surface characterization. Furthermore, we illustrate how a static 3D phase and/or amplitude object can also be reconstructed tomographically by illuminating it at multiple angles using this modified setup. The object will be 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. Finally, a reconfigurable hardware maybe employed for synchronization of the CCD and the TL-TIE lens.

9495-39, Session PTue

3D subsurface imaging of crustal rocks using components of electromagnetic radiations based on Maxwell theory prior seismic events in situ

Umesh P. Verma, Ranvir N. Nandan, Patna Science College (India); Madhurendra Nath Sinha, Patna Iniversity Geology Department (India)

Continuous observations on imagery of TEC , MMC and OLR data available through NOAA and IPS and IRS kalpana satellites and RT basis could reveal interesting pattern of variations in the components of electromagnetic radiation induced prior seismic events. With sincere interpretation after analysis not only provide pre- seismic events'information but at the same time generates 3D imaging of subsurface stressed block of sub crustal rocks.undrer stress the rock volume induces EM radiation at LIA and atmospheric condition transmitted in form of TEC(Total electron Content) and MMC(Multiple magnetic components) and OLR (outgoing long wave radiation) ;which are recorded by said satellites on real time basis. Using FFT and normal numerical modelling 3 D images are interpretated undergoing geophysical and geochemical changes prior the seismic events. The technique is best alternative for infrared and hyperspectral imaging to decipher the subsurface imagery only with the satellite signals' 'variation.

With the tracing technique of all noted observations and plotting on the 3axes system the variation trend gives informative view of the changes taking place in the geophysical and geochemical properties of the rocks. On the basis of trend of signals obtained and theirs' nature of propagation a profile of the rocks inferred(available0) with intriguing properties can be deciphered . These entire processing are undertaking at the sub crustal volume.

9495-40, Session PTue

Color reconstruction of computer-generated hologram for real scenes using a light field camera

Yutaka Endo, Takashi Kakue, Tomoyoshi Shimobaba, Tomoyoshi Ito, Chiba Univ. (Japan)

To calculate computer-generated holograms (CGHs) of real scenes under incoherent light, many capturing systems have been proposed. Integral imaging is a technique to capture three-dimensional information and used for calculating CGHs. However, conventional integral imaging systems would be relatively large. Recently lenslet-based light field cameras attract wide interests, and some products are on the market. The light field cameras are small and easily obtainable.

In this paper, we show a process to calculate a CGH of real scenes using a consumer light field camera, Lytro, and show the results of color reconstruction of the CGHs. Since Lytro is relatively small, portable and inexpensive compared to conventional integral imaging systems, it would be convenient to construct a capturing system for CGH calculation. The CGH calculation is performed by the conversion of a light field into a wavefront using Fourier transform of each sub-image of Lytro. Before the conversion, we perform light field rendering to match the sampling of the light field to the conditions of a display device for the CGHs. For color reconstruction, we calculate three CGHs with red, blue and green wavelengths and superpose those reconstructed images. Experimental results demonstrate that the CGH calculation and its color reconstruction are correctly performed.

9495-41, Session PTue

Compressive holography reconstruction using phase-shifting interferometry

Cheng Zhang, Chuan Shen, Hong Cheng, Fen Zhang, Anhui Univ. (China); Kaifeng Liu, Quanbing Zhang, Anhui University (China); Sui Wei, Anhui Univ. (China)

In classical compressive holography (CH), which based on the Gabor holography setup, two nonlinear terms are inherent in the intensity recorded by a 2D detector arrays, the DC term and the squared field term. The DC term (the term at the origin) can be eliminated by filtering the Fourier transform of the interference irradiance measurements using appropriate high-pass filter near the zero frequency. The nonlinearity caused by the squared field term can be neglected and modeled as a error term in the measurement. However, the above assumptions are significantly limited, which yields the degradation of reconstruction quality.

In this paper, an novel scheme using phase-shifting method is presented. To accurately recover the complex optical field caused by the propagation of the object, without the influence of the DC term and the squared field term, a very effective method for removing these two terms is introduced. The complex optical field of the 3D object and the complex optical field at the detector plane can be precisely represented by a linear mapping model. The complex optical field at the recorder plane is obtained by phase-shifting interferometry with multiple shots. Then, the corresponded complex optical field at the detector plane can be successfully extracted from multiple captured holograms using conventional four phase-shifting interferometry. From such complex optical field at the record plane, including the amplitude and phase information, the complex optical field of the 3D object can be reconstructed via a optimization procedure. Numerical results demonstrate the effectiveness of our proposed method.

9495-42, Session PTue

Viewing zone control of super multi-view display with directional backlight

Kenji Hirano, Jin Miyazaki, Tomohiro Yendo, Nagaoka Univ. of Technology (Japan)

A super multi-view display provides three-dimensional images by emitting a lot of rays of different colors depending on the direction from each point on the display. It provides smooth motion parallax without special glasses, and it is expected that the observer is free from the visual fatigue caused by the accommodation-vergence conflict. However, a huge number of pixels are required on a display device because high-density rays are required for good quality images and each ray needs corresponding pixel. We proposed a new method to reduce the required number of pixels by limiting rays emitted to only around observer's pupils.

The display is based on the lenticular method. As stated above, the rays should be shot out to only around observer's pupils. Therefore, the lenticular lens of which viewing zone angle is narrowed is used. But, due to the characteristics of the lenticular lens, the same image is seen repeatedly from different positions out of the viewing zone. It is called side lobe. Because of the side lobes, the rays for one eye enter the other eye. To suppress these side lobes, we proposed the lenticular lens is illuminated by the directional light. The direction of the directional light has to be changed to follow the observer's eye.

We implemented optical designs based on the technique as mentioned above, and we produced a prototype display. We experimented with consideration of change of viewing angle and distance.

We confirmed usefulness of the proposed display by these experiment result.

9495-43, Session PTue

The use of 3D scanning for sporting applications

Kevin J. Friel, Pann Ajjimaporn, Jeremy Straub, Scott Kerlin, Univ. of North Dakota (United States)

A low-cost, visible light 3D Scanner has been developed which uses fifty cameras attached to Raspberry Pi single-board computers. This scanner is able to capture even minute details of a subject and collect structural, texture and coloration detail. These models can be 3D printed or displayed on screen for visualization; they can also be computationally analyzed. This paper considers the application of 3D scanning and the analysis of collected data to improving sporting performance. Sports player spend tireless hours trying to improve elements of their gameplay. A basketball player might seek to understand the current mechanics of and to optimize a jump shot, while a runner focuses on posture and stride issues. One area of particular benefit, which the scanner that has been developed at the University of North Dakota is well-suited for is sports where performance is heavily related to posture, stance, and positioning. One such sport is golf. In golf, a player may spend significant time trying to perfect their stance and swing to create the perfect shot. There are many times where the player may believe that the swing is perfect, but the reality is a different story. The 3D Scanner and visualization techniques can, potentially, correct this misunderstanding as well as aiding in improving detected issues. The 3D Scanner can show the problems in the player's grip on the club, how far back they are taking the swing and/or how bent their knees should be. This paper continues with

a discussion of the challenges of assessing sporting activities, particularly related to golf and hockey, and the utility provided by doing so. It discusses how a visible light scanner can be particularly useful for scanning combined human-and-object targets. It concludes with a discussion of how this approach can apply to other sports.

9495-44, Session PTue

The use of 3D scanning for wellness assessment purposes

Pann Ajjimaporn, Kevin J. Friel, Jeremy Straub, Scott Kerlin, Univ. of North Dakota (United States)

This paper considers the use of a 3D scanner for wellness assessment and monitoring. It begins with a discussion of the various ways that the scanner could prospectively aid this type of application. The efficacy of multiple types of scanners (optical, blue light and laser) is discussed, relative to the identified applications. The paper then focuses on one particular application: wellness assessment through patient body visualization with a visible light 3D scanner. This scanner can be used to allow a patient or doctor to view different perspectives of different parts of the body (for an extended period of time, if required for diagnosis), in a way that a single picture couldn't or which might require an invasive or uncomfortable posture. It may also facilitate a doctor seeking out a specialist opinion without requiring the patient to physically visit the specialist.

The scanner can provide a detailed rendering of the gesture and the natural position of the different parts of the patient's body. For example, for a patient undergoing spinal cord therapy, 2D pictures could show the person in the difference posture; however, the perspectives offered might be vague and the differences that could be viewed from the perspectives that images were captured from might be minimal. With the help of a 3D Scanner, the patient and his or her doctor can see him or herself from a 3D perspective that can be spun around, looked at from all the directions that the patient or doctor would want to look at and provide an opportunity for the patient to see the improvement of their body or to see if the posture has improved over time. A similar approach could also be utilized for weight loss monitoring, where a patient could view the impact of their diet, exercise and/or other activities over time. The paper concludes by discussing how the work performed relative to these two limited applications can be expanded upon to aid other medical applications.

9495-45, Session PTue

Gesture recognition and space-division multiplexing enabled fog based interactive 360-degree viewable display

Praneeth K. Chakravarthula, Indian Institute of Technology Madras (India); Pattie Maes, Massachusetts Institute of Technology (United States)

Substantial research is being done in the field of 3D Displays. Most present day 3D displays uses special films/glasses to visualize the 3D content. The drawbacks of such a system is that the image cannot be viewed in multiple viewpoints and also it causes visual discomfort. Though Holographic displays are present, they offer only a limited viewing angle. Also, one cannot get rid of the screen and they do not allow the user for direct interaction with the 3D image. We present a novel fog based "immaterial" 3D display, which solves most of the above problems. The concept of the proposed display is similar to 360-degrees viewable 3D diplays which utilize projection of multiple images such as Hitachi's transport or Sony's RayModeler. But this stereoscopic display enables observers to not only visualize the 3D shape of virtual objects but also to be able to touch them as if they were real, and interact. This idea of fog based displays has been explored previously, majorly for 2D visualizations (e.g. [Rakkolainen et al. 2005]) and also for 3D visualization (e.g. [Asuka Yagi et al.]). But our system consists of a cylindrical fog screen with a gesture recognition system. The cylindrical fog screen which facilitates space division multiplexing of visual information can be used to visualize different content or can be used to visualize a single virtual object in its full-parallax view when used with multiple projectors. And the gesture recognition system enables the user to interact with the 3D objects rendered on the cylindrical screen directly with hands.

9495-46, Session PTue

Projection type transparent 3D display using active screen

Hiroki Kamoshita, Tomohiro Yendo, Nagaoka Univ. of Technology (Japan)

Equipment to enjoy a 3D image, such as a movie theater, television and so on have been developed many. So 3D video are widely known as a familiar image of technology now.

The display representing the 3D image are there such as eyewear, naked-eye, the HMD-type, etc. They has been used for different applications and location.

But have not been widely studied for the transparent 3D display.

If transparent large 3D display is realized, it is useful to display 3D image overlaid on real scene in some applications such as road sign, shop window, screen in the conference room etc.

As a previous study, to produce a transparent 3D display by using a special transparent screen and number of projectors is proposed.

However, for smooth motion parallax, many projectors are required.

In this paper, we propose a display that has transparency and large display area by time multiplexing projection image in time-division from one or small number of projectors to active screen.

The active screen is composed of a number of vertically-long small rotate mirrors.

It is possible to realize the stereoscopic viewing by changing the image of the projector in synchronism with the scanning of the beam.

3D vision can be realized by light is scanned.

Also, the display has transparency, because it is possible to see through the display when the mirror becomes perpendicular to the viewer.

We confirmed the validity of the proposed method by using simulation.

9495-47, Session PTue

Noise reduction in holographic reconstruction by combining two spatial light modulators

Thibault Leportier, Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of); Jung-Young Son, Konyang Univ. (Korea, Republic of)

One of the issues in holographic display is the presence of the zeroth order and the twin image which are degrading the image quality of the reconstructed object. A common solution introduces an off-axis configuration. However the spatial separation of the three contributions imposes constraints on the resolution and the size of the hologram. In addition, the spatial light modulators (SLM) currently available present limitations in terms of resolution and fill factor. Recently, different methods have been proposed to display complex information, and therefore get rid of the twin image. One approach is to use a grating to combine the real and imaginary parts of the holographic data. It requires only a single SLM, but the resolution is low as the SLM is divided in two to display the two components of the data. The grating period that should be used is also strongly dependent of the wavelength and the hologram size. It imposes strong restrictions on the system's tolerance. Another approach is to combine two SLMs. In this paper we propose a new approach to make use

of a polarizing beam splitter and a wave-plate to exploit the polarization properties of the light and combine the wavefronts coming from two SLMs. One SLM is used to display the hologram while the other compensates the background noise coming from the diffusion of the input light by the pixels and the intrinsic periodic structure of the SLM.

9495-48, Session PTue

Evaluating visual discomfort in stereoscopic projection-based CAVE system with a close viewing distance

Weitao Song, Beijing Institute of Technology (China) and Univ. of Connecticut (United States); Dongdong Weng, Dan Feng, Yuqian Li, Yue Liu, Yongtian Wang, Beijing Institute of Technology (China)

As one of the popular immersive Virtual Reality (VR) systems, stereoscopic cave automatic virtual environment (CAVE) system is typically consisted of 4 to 6 3m-by-3m sides of a room made of rear-projected screens. While great efforts have been made to reduce the size of the projection-based CAVE system, the issue of asthenopia caused by lengthy exposure to stereoscopic images in such CAVE with a close viewing distance has yet to be dealt with. In this paper, we propose a light-weighted approach which utilizes a convex eyepiece to reduce visual discomfort induced by stereoscopic vision. An empirical experiment was conducted to examine the feasibility of convex eyepiece in a large depth of field (DOF) at close viewing distance both objectively and subjectively. The result shows the positive effects of convex eyepiece on the relief of eyestrain.

9495-49, Session PTue

Conditions in order to maintain the viewing zone in autostereoscopic display

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)

In general, autostereoscopic display provides stereoscopic vision by using an optical plate, such as a parallax barrier or lenticular. The Optimum View Distance(OVD) and viewing zone formed in formed in optical plate is an important factor to observe the correct stereoscopic vision.

However, when a glass is used in the process of manufacturing the optical plate, problem occurs in the formation of the OVD and viewing zone by the refractive index of the substrate. By each refractive index which causes different angles of the viewing zone and the display, reduce the OVD. In this paper, parallax barrier and substrate were used in the experiment and to predict mathematically to figure the changes in OVD depended by each usage conditions.

To maintain the distance between the flat panel display and the autostereoscopic optical plate, in the presence of a glass substrate, it is demanded to employ the method with minimum affect by the refractive index.

AS results of the experiment, a method that is able to provide a stereoscopic with minimal impact, a glass substrate for fixing the optical plate has been confirmed that when the position in the direction of the viewer, has the least effect. Thus in order to deform OVD by each angles of the viewing zone, it is important to maintain the spacing between the optical plate and flat panel display.

9495-50, Session PTue

Impact of lighting and attire on 3D scanner performance

Dakota J. Feist, Jeremy Straub, Scott Kerlin, Univ. of North Dakota (United States)

This paper considers the impact of lighting and attire on the performance of a previously created low-cost 3D scanning system. It considers the effect of adjusting the lighting configuration and of the subject's clothing on the quality of the scans and the number and types of objects that can be scanned. The experimentation performed tested different types (colors and textures) of clothing to assess which produced the best scans and multiple lighting configurations.

The project started with primarily testing different clothing color configurations. Dark and baggy clothing, like hoodies and cargo shorts did not scan well. These items would generally render, but would be distorted or appear muddy. However, if the dark colors are offset by something brighter, then render quality improved. If the colors were all really bright, on the other hand, they won't render at all. Based on our testing, a light brown shirt and light blue jeans produced the best results.

Several lighting configurations were also considered. First, normal room lighting was tested. Then fluorescent lights were incorporated into the scanning chamber. Both were placed at the top of the room with one in front of the user, and one near the back. This improved performance - particularly in the area of the legs; however it caused glair on the top of the head.

The paper includes a summary of performance across numerous combinations of lighting and clothing configurations. Future work will include testing the impact of using other lighting including applying light defusers to the existing fluorescent lights, and adding lights with de-fusers in front and behind the person being scanned. The paper concludes with a discussion of scanner efficacy for various applications, based on the data collected.

9495-51, Session PTue

Integrating visible light 3D scanning into the everyday world

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

Visible light 3D scanning offers the potential to non-invasively and nearly non-perceptibly incorporate 3D imaging into the everyday world. Applications of this technology can increase productivity and security and enhance profitability. This paper considers the various possible uses of visible light 3D scanning technology. It discusses multiple possible usage scenarios including in hospitals, security perimeter settings and retail environments. The use of the scanner in each prospective example application is discussed and its utility therefor is assessed. A value model is considered which compares estimates of the cost (including monetary costs and other possible cost sources, such as legal liability and the loss of goodwill from possible misuse or failure) and value produced by the technology (for both the business / organization) and individual.

From this, a framework for assessing the efficacy of visible light 3D scanning for a given application is derived (and the utility of the visible light approach is compared to other scanning approaches such as those using blue light or lasers). Factors that drive cost and benefit are identified and the impact of these factors' implication in a usage scenario on cost and benefit is considered.

The paper also discusses ethical and legal considerations relevant to real-world use. This extended discussion considers prospective legal regulations regarding and restrictions on the use of this type of scanning technology. It also considers individuals' expectations across multiple scenarios and the impact of these expectations on how a scanner could be used without being perceived as invasive and impairing the individual's goodwill. From all of this, the paper concludes by presenting a decision making framework for scanner incorporation into an application.

9495-52, Session PTue

360-degree three-dimensional digitization of human torso by using multiples projection-acquisition systems

Carlos Ricardo Contreras Pico, Andrés Leonardo González Gómez, Jaime Enrique Meneses Fonseca, Univ. Industrial de Santander (Colombia)

In the field of medicine esthetic has been developed a set of non-invasive techniques to mold the body, such as Blepharoplasty, Mastoplasty, and Lipoaspiration, among others. At present, non-invasive therapeutic procedures are applied: Mesotherapy, Vacuum Therapy or Endermologie and Ultrasonic Hydrolipoclasia, etc., by using a set of modeler systems with high technology, which permit to obtain esthetic results that are demonstrated qualitatively. Many authors conclude that although the results are demonstrated qualitatively, there are not appropriate studies that verify quantitatively and locally the volume variations from objective and precise measurements. As consequence of this situation, the companies that manufacture systems to treatment and specialized academies in the matter, restrict your participation in the market and they reduce the competitiveness of your products front to others procedures.

In this paper the development of a system to digitize the human torso is shown. The system has been developed in order to evaluate, primarily, the effectiveness of the therapeutic methods mentioned above; however, the applications of such a system would be multiple in various fields. The system consists of four projection-acquisition modules and it is based on the fringe projection technique and the phase shifting algorithm. The calibration procedure, which is implemented to determine the transformations that allow to locate the point clouds, which are acquired by each of the systems, in a single coordinate system is carried out from the digitization of a control object, in this case a parallelepiped.

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9496-1, Session 1

Remote stress detection using visible (RGB) camera

Balvinder Kaur, Sophia Moses, Megha Luthra, Vasiliki N. Ikonomidou, George Mason Univ. (United States)

Abstract: Heart rate variability (HRV) can be an important indicator of several conditions that affect the autonomic nervous system, including traumatic brain injury, post-traumatic stress disorder and peripheral neuropathy. Recent work has shown that some of the HRV features can potentially be used for distinguishing a subject's normal mental state from stressed one. In all of these past works, HRV analysis is performed on the cardiac activity data acquired by conventional electrocardiography electrodes, which may introduce additional stress and complexity to the acquired data. In this paper we use remotely acquired time-series data extracted from the human facial skin reflectivity signal during rest and stressed conditions to compute HRV driven features. We further apply a set of classification algorithms to distinguishing stressed from normal conditions. To determine heart beat signal from the facial skin reflectivity, we apply 1) Principal Components Analysis (PCA) for denoising signals, 2) Independent Component Analysis (ICA) for source selection, 3) Bandpass filters for further denoising. To determine the signal peaks to extract the RR-interval time-series, we apply 1) a threshold-based detection technique and 2) additional peak conditioning algorithms. To classify RR-intervals, we explored classification algorithms that are commonly used for medical applications such as 1) logistic regression and 2) linear discriminant analysis (LDA). Goodness of each classifier is measured in terms of sensitivity/specificity. Results from each classifier are then compared to find the optimal classifier for stress detection. This work, performed under an IRB approved protocol, provides initial proof that remotely-acquired heart rate signal can be used for stress detection. This result shows promise for further development of a remote-sensing stress detection technique both for medical and deception-detection applications.

9496-2, Session 1

Breast lesion segmentation using a three-dimensional active contours without edges approach with a GPGPU implementation

Anke Meyer-Baese, Florida State Univ. (United States)

A three-dimensional implementation of the Active Contours Without Edges (ACWE) algorithm using OpenCL is presented. The proposed algorithm uses the General-purpose computing on graphics processing units (GPGPU) to accelerate the original model by parallelizing two main steps of the segmentation process, the computation of the Signed Distance Function (SDF) and the evolution of the segmented volume. The proposed energy function, of the Active Contours algorithm, incorporates knowledge of the kinetic curves of common breast lesions to improve the segmentation. A dataset of 46 dynamic contrast-enhanced (DCE) breast MRI images, from Maastricht University Medical Center, is used to test and validate the proposed algorithm. Compared with an optimal sequential implementation, the proposed algorithm obtains speedups of ten, on a GeForce GTS 450 video card, in most of the images. The segmentation process is visualized in real time with a graphical user interface (GUI) developed with Qt and OpenGL. The described work obtains volumes of breast lesions in a fast way by taking advantage of the computational resources of the video cards and it allows the physician to visualize the results with multiple views. This software can be used to segment breast lesions of DCE MRI images for preoperative staging, evaluation after chemotherapy, and for screening of women at high risk of developing cancer.

9496-3, Session 1

Remotely detected differential pulse transit time as a stress indicator

Balvinder Kaur, Elizabeth Tarbox, Marty Cissel, Sophia Moses, Megha Luthra, Nhien Tran, Misha Vaidya, Vasiliki N. Ikonomidou, George Mason Univ. (United States)

Abstract: The human cardiovascular system, largely controlled by the autonomic nervous system (ANS), is one of the first sites where one can see the "fight-or-flight" response due to the presence of external stressors. The main cardiovascular-related measure for stress detection remains the heart rate (HR). The combination of HR with heart rate variability (HRV) analysis allows detection of changed parameters in the ANS control system and therefore provides a reasonable power of stress detection. In this paper, we investigate the possibility of a second measure: Pulse transit time (PTT), which refers to the time that is required for the blood pressure wave to cover the distance from the heart to a defined remote location in the body. Loosely related to blood pressure, PTT is a measure of blood velocity, and is also implicated in the "fight-or-flight" response. We define the differential PTT (dPTT) as the difference in PTT between two remote areas of the body, such as the forehead and the palm. Expanding our previous work on remote heart rate detection from visible spectrum videos, we built a system that remotely measures dPTT. Human subject data were collected under an IRB approved protocol from 15 subjects both under normal and stressed conditions and are used to initially establish the potential use of remote dPPT detection as a stress indicator.

9496-4, Session 1

High accuracy optical flow estimation based on robustification variants and novel computer-aided diagnosis systems applied to breast MRI

Anke Meyer-Baese, Florida State Univ. (United States)

Motion compensation represents an important pre-requisite for a correct computer-aided diagnosis of lesions in breast MRI. We extend and improve the optical flow algorithm described by Brox et al. (2004) and introduce robustification variants for applicability to breast MRI. The original algorithm is based on an energy functional for computing the optical flow and on three assumptions, a brightness constancy assumption, a gradient constancy assumption, and a discontinuitypreserving spatio-temporal smoothness constraint. We study two types of robustification, a joint and separate, and evaluate both methods based on the computed smaller angular errors. In a subsequent computer-aided diagnosis system we evaluate the developed method on breast MRI images comprising diagnostically challenging lesions. The proposed method for motion compensation shows improved lesion detection for this demanding clinical application.

9496-5, Session 1

Catheter ultrasound for cross-sectional imaging and drug delivery to vessel wall (Biomedical Wellness Award Invited Presentation) *(Invited Paper)*

John A. Hossack, Univ. of Virginia (United States)

Current methods for delivery of an anti-restenosis drug to an arterial vessel wall post-percutaneous transluminal angioplasty and stent placement are limited in terms of drug choice, dosing level, and ability to assure drug coverage between the struts of a drug eluting stent. An ideal solution for the diagnosis and treatment of vascular disease must involve high-resolution imaging with cross-sectional characterization of the vessel wall and the means to provide a com-prehensive and versatile therapy that can be completed within a single catheterization procedure. Intravascular ultrasound (IVUS) provides real-time, radiation-free, imaging and assessment of atherosclerotic disease in terms of anatomical, functional and molecular information. In this presentation, the design of a dual imaging / therapy IVUS catheter is described and results doc-umenting gene and drug delivery reported. Microbubbles and drug / gene (shell associated or co-injected) are dispensed from the catheter tip. Using this approach, it becomes possible to address the need for complete vessel wall coverage and achieve delivery in regions poorly addressed us-ing conventional stent-based approaches (e.g. near bifurcations). Additionally, we propose to in-tegrate microfluidic devices directly within the catheter to enable real-time production of mi-crobubbles. By placing the microfluidics device in the catheter, the need for long-term mi-crobubble stability is mitigated. This tolerance for limited stability facilitates the rapid production of microbubbles (> 100,000 microbubbles/s) and therefore meets requirements in order to address realistic vessel segments within the limited available time in the catheter lab setting. A range of in vitro, ex vivo and in vivo results are presented. Our most recent results involve a demonstration in a pig model of coronary balloon angioplasty that produced a 33% reduction in neointima formation versus a drug plus microbubble, but no ultrasound, control.

9496-6, Session 2

Quantitative analysis of integrated chromosome 19 transcriptomic and proteomic data sets derived from glioma cancer stem-cell lines

Anke Meyer-Baese, Florida State Univ. (United States)

The inherent genomic instability in gliomas results in chromosomal duplications, amplifications of specific genes, and activating mutations. Chromosome 19 is linked to glioma by 1p/19q codeletions, which are a positive prognostic indicator: 123 months mean survival versus 16 months in patients with tumors that are 1p/19q intact.

We perform a quantitative analysis on transcriptomic and proteomic data sets derived from glioma-derived cancer stem cells (GSCs) based on nonlinear feature extraction methods and unsupervised clustering.

In our analysis, we determine a high degree of similarity in overall protein expression patterns between some specific GSCs.

Taken together, these results indicate that the various GSC cell line classes show similar expression patterns for chromosome 19 proteins. Our results have expanded the knowledge of the role of chromosome 19 beyond the well-known impact of 1p/19q codeletion. Our findings may have relevance for selection of GSC lines for testing responses to preclinical and clinical compounds.

9496-7, Session 2

Dynamical complex network theory applied to the therapeutics of brain malignancies

Anke Meyer-Baese, Florida State Univ. (United States)

Controlling regions in signaling networks represent key nodes to control the dynamics of the network to a desired state corresponding to a drug-response in brain cancer patients. We propose to apply pinning control in combination with a constrained evolutionary computation method to localize these driver nodes.

We checked whether the controlling regions depend on the number of driver nodes and whether the primary driver nodes have a large in-degree and a small out-degree. At the same time we will unveil the potential controlling rules.

Our proposed research is expected to further our understanding of therapeutics and will be beneficial for neuropharmacology by directly targeting these regions through novel treatment strategies.

9496-26, Session 2

A new EEG measure using the 1D cluster variation method

Alianna J. Maren, Themasis Associates (United States)

A new information measure, drawing on the 1-D Cluster Variation Method (CVM), describes local pattern distributions (nearest-neighbor and next-nearest neighbor) in a binary 1-D vector in terms of a single interaction enthalpy parameter h for the specific case where the fractions of elements in each of two states are the same ($x1=x2=0.5$). An example application of this method would be for EEG interpretation in Brain-Computer Interfaces (BCIs), especially in the frontier of invariant biometrics based on individual Grand Mother favorite image sets as the unique stimulus and response.

This measure is obtained by mapping EEG observed configuration variables (z1, z2, z3 for next-nearest neighbor triplets) to h using the analytic function giving h in terms of these variables at equilibrium. This mapping results in a small phase space region of resulting h values, which characterizes local pattern distribution in the source data. The 1-D vector with equal fractions of units in each of the two states can be obtained using the method for transforming natural images into a binarized equi-probability ensemble (Saremi & Sejnowski, 2014; Stephens et al., 2013). The 1-D space-filling curve demonstrated 20 dB lower baseline using the Peano-Hilbert method (cf. SPIE ICA etc. by Hsu & Szu, 2014) that might optimize the COTS 1-D BCI baseball hat, resulting in a convenient 3-D lab-tethered EEG in 1-D CVM equi-probable binary vector for Smartphone wireless display.

9496-8, Session 3

Reducing weight precision of convolutional neural networks towards large-scale on-chip image recognition

Zhengping Ji, Ilia Ovsiannikov, Yibing Wang, Lilong Shi, Qiang Zhang, Samsung Semiconductor, Inc. (United States)

Deep learning drew considerable research attention in recent years. Various deep learning architectures, such as convolutional deep neural networks, deep belief networks and auto encoder decoders have been developed to provide state-of-the-art solution in a variety of artificial intelligence and computer vision tasks, including (large-scale) visual object recognition, automatic speech recognition, natural language processing, and music/audio signal processing. Till now, the main efforts of deep learning have been focused on the software implementation, in the aspects of network architectures, learning optimization and demonstration of applications with bench-marking performance. Yet the hardware implementation endowing more powerful on-board behaving is still limited. Transforming the advancement of deep learning from current software implementation to fast and compact chip solution, especially under mobile platform is of great importance for next-generation hand-held products and wearable devices.

Major challenges in achieving deep learning chips lie in the constraints of hardware size and power consumption. For instance, the software implementation can enjoy a cluster of high performance computers with huge storage space and unlimited power supplies, but this becomes implausible when considering a centimeter size chip running on a standalone battery. One efficient solution to reduce storage space and power consumed for calculation on chip is to reduce the precision of model configurations, i.e., the connection weight and internal responses for deep learning architecture. This paper is aimed at creating such a deep learning system running with low bit resolution and in the meanwhile maintaining good performance for image recognition task. A popular deep learning architecture -- Convolutional Neural Networks (CNN), is selected given two factors: (1) its hardware favorableness in local computation for parameter reduction and (2) outstanding performance in solving image recognition problems.

We proposed server-device quantization scheme to reduce bit resolution of CNN for image recognition tasks. On the server cloud, we first train a Convolutional Neural Network using back propagation algorithm, where resolution bits for both input and weight are double precision (64 bits). Then we perform a new quantization method – supervised iterative quantization to reduce the bit resolution of learned network weights. This process involves intensive data learning process (both unsupervised and supervised) and expensive computation, so we perform it on server. After that, the network configuration and quantized weight with low bit resolution are loaded to the hardware device to recognize coming input in real-time. Considering the hardware side, however, the optimized but expensive quantization becomes infeasible for real-time input. Thus, we adopted a uniform quantization instead for the input and network responses to guarantee low on-chip load and fast running speed. The convolutional neural network with reduced weight precision thus receives quantized image input, generates low-bit responses and performs recognition of responses for class output.

The Convolutional Neural Network with reduced weight and input/response precision is demonstrated in recognizing two types of images. One is hand-written digit images and the other is real-life images in office scenarios. Both results showed that the network is able to maintain the original performance even though the bit resolution of both weight and input are largely reduced, e.g., from 64 bits to 4-5 bits.

9496-9, Session 3

An evaluation into the effectiveness of machine learning algorithms in traffic pattern prediction using field and simulation data

Nnanna N. Ekedebe, Nicolas Dolphin, Towson Univ. (United States)

Without intelligent transportation systems (ITS)/Vehicular ad hoc networks (VANETs), road traffic congestions will continue to exacerbate leading to increases in wasted time, gas, and other harmful environmental emissions. Consequently, having prior knowledge of the congested condition of a roadway can be invaluable especially in emergency situations.

Owing to the aforesaid, using several machine learning algorithms, we evaluate their prediction accuracy in determining future traffic patterns. Our training set consists of six weeks of real-world traffic data from August, 1st 2012 to September, 27th 2012 in the Maryland (MD)/Washington DC and Virginia (VA) areas.

Our results show that the predictive accuracy of our evaluated machine learning algorithms depend on factors such as time of day, and prediction window/interval. Generally speaking, the higher the prediction window, the lower the prediction accuracy of algorithms, and vice versa. In addition, transportation planning authorities/stakeholders in our selected study area can directly use our results to better understand the factors that influence the predictive accuracy of machine learning algorithms used in the transportation domain, with a view of selecting the one most suited for use in specific scenarios. This is especially true because most studies simulate very simplistic traffic conditions that either void of real-world data, realistic road networks, or both.

9496-10, Session 3

A generalized LDA framework through 6W

Jeffrey C. Jenkins, The Catholic Univ. of America (United States); Rutger Van Bergem, George Mason Univ. (United States); Charles Sweet, LoftMind, Inc. (United States); Eveline Vietsch, Georgetown Univ. Medical Ctr. (United States); Harold H. Szu, The Catholic Univ. of America (United States); Masud Cader, American Univ. (United States); Dalila Benachenhou, George Washington Univ. (United States)

Large Data Analysis (LDA) has become a reachable multi-disciplinary goal in recent years due in part to high performance computers and algorithm development, as well as the availability of large data sets. However, the experience of Machine Learning (ML) and information communities has not been generalized into an intuitive framework that can be used directly by researchers in several disciplines. How can the human brain uncover patterns, association and features in real-time, real-world data? There must be a general strategy used to transform raw signals into useful features, but representing this generalization in the context of our information extraction tool set is lacking. The data exploration phase of data mining is a prime example of this unspoken, ad-hoc nature of ML – the Computer Scientist works with a Subject Matter Expert (SME) to understand the data, and then build tools (i.e. classifiers, etc.) which can benefit the SME and the rest of the researchers in that field. We ask, why is there not a tool to represent information in a meaningful way to the researcher asking the question? Meaning is subjective across disciplines, so to ensure robustness, we draw examples from several disciplines and propose a generalized LDA framework for independent data understanding. Then, we explore the concept of adaptive Information resolution through a 6W unsupervised learning methodology feedback system.

9496-11, Session 3

Earth mover's distances of feature vectors in large data analyses

Henry Chu, Anurag Singh, Michael A. Pratt, Univ. of Louisiana at Lafayette (United States)

The earth mover's distance (EMD) measures the difference of two feature vectors that is related to the Wasserstein metric defined for probability distribution functions on a given metric space. The EMD of two vectors is based on the cost of moving the content of individual elements of an anchor vector to match the distribution of a target vector. The EMD is a solution to a transportation problem. We present results of using EMD in large data analysis problems such as those for health data and image data.

9496-12, Session 3

Compressive sensing solutions through minimax optimization

Liyi Dai, U.S. Army Research Office (United States)

This paper is concerned with the basic issue of the robustness of

compressive sensing solutions in the presence of uncertainties. In particular, we are interested in compressive sensing solutions under unknown modeling and measurement inaccuracies. The problems are formulated as minimax optimization. Exact solutions are derived through the approach of Alternating Direction Method of Multipliers. Numerical examples show the minimax problem formulations indeed improve the robustness of compressive sensing solutions in the presence of model and measurement uncertainties.

9496-13, Session 4

Hypothesis on human eye perceiving optical spectrum rather than an image

Yufeng Zheng, Alcorn State Univ. (United States); Harold H. Szu, The Catholic Univ. of America (United States)

It is a common knowledge that we see the world because our eyes can perceive an optical image. A digital camera seems a good example of simulating the eye imaging system. However, the signal sensing and imaging on human retina is very complicated. There are at least five layers (neurons) along the signal pathway: photoreceptors (cones and rods), bipolar, horizontal, amacrine and ganglion cells. To sense an optical image, it seems that photoreceptors (as sensors) plus ganglion cells (converting to electrical signals for transmission) are good enough. Image sensing does not require ununiformed distribution of photoreceptors like fovea. For example, why don't we feel the "blind spots" (never fibers exiting the eyes)? Similar situation happens to glaucoma patients who do not feel their vision loss until 50% or more nerves died. Now our hypothesis is that human retina initially senses optical spectrum rather than optical image. Due to the symmetric property of Fourier spectrum the signal loss from a blind spot or the dead nerves (for glaucoma patients) can be recovered. Eye logarithmic response to input light intensity much likes displaying Fourier magnitude. The optics and structures of human eyes satisfy the needs of optical Fourier spectrum sampling. It is unsure that where and how inverse Fourier transform is performed in human vision system to obtain an optical image. Phase retrieval technique in compressive sensing domain enables image reconstruction even without phase inputs. The new spectrum-based imaging system can tolerate up to 50% of bad sensors/pixels, adapt to large dynamic range (with logarithmic adaption), etc. More details will be presented in the paper.

9496-14, Session 4

Radar sensing displayed through optics

Harold H. Szu, Charles C. Hsu, The Catholic Univ. of America (United States); Michael J. Wardlaw, Office of Naval Research (United States); Jefferson M. Willey, U.S. Naval Research Lab. (United States)

No Abstract Available

9496-15, Session 4

Optical sensing cameras

Harold H. Szu, The Catholic Univ. of America (United States); Jae Hoon Cha, A. Lynn Abbott, Virginia Polytechnic Institute and State Univ. (United States); Keith A. Krapels, The Univ. of Memphis (United States)

No Abstract Available

9496-16, Session 5

Automatic organization and signal processing of databases (Large Data Analysis Award Invited Presentation)
(Invited Paper)

Ronald R. Coifman, Plain Sight Systems, Inc. (United States)

We describe a general methodology to associate with a database, viewed as a matrix or a higher dimensional tensor, an analytic processing tool kit, which can be used to perform signal processing on the data, from denoising to filling in missing entries, or compression.

The system builds two geometries in duality, one on the rows the other on the columns allowing for filtering and matching using natural earth mover distances between data points.

Applications to processing sensor data, psychological profiles, text documents ,and others will be given.

9496-17, Session 5

VoIP attacks detection engine based on neural network

Jakub Safarik, V?B-Technical Univ. of Ostrava (Czech Republic); Jiri Slachta, Cesnet z.s.p.o. (Czech Republic)

The security is nowadays crucial for any system, especially communications. One of the most successful protocols in the field of communication over IP networks is Session Initiation Protocol. It is an open-source project used by different kind of application, both open-source and proprietary. High penetration and text-based principle made SIP number one target in IP telephony infrastructure, so security of SIP server is essential. To keep up with hacker and detect potential malicious attacks, security administrator needs to monitor and evaluate SIP traffic in the network. But monitoring and following evaluation could easily overwhelm the security administrator in networks, typically in networks with a number of SIP servers, users and logically or geographically separated networks. The proposed solution lies in automatic attack detection systems. The article covers detection of VoIP attacks in such a system based on artificial intelligence neural network. A honeypot applications running in the real network gather reliable attack information. The honeypot application runs in various part of the network and creates a distributed net of detection nodes. The input for neural network contains real attack data detected on honeypots. From same honeypots, I prepare training set with specific attack sets of various attack types, which uses a backpropagation algorithm learning. The automatic classification on a centralized server with low false positive detection reduce the cost of attack detection resources. Whole detection system uses modular design for easy deployment in final infrastructure. The centralized server collects and process detected traffic and maintains whole distributed network of detection nodes.

9496-18, Session 5

Thermal image enhancement based on blind source separation and multiple spectral measurements

Jae Hoon Cha, U.S. Army Night Vision & Electronic Sensors Directorate (United States); A. Lynn Abbott, Virginia Polytechnic Institute and State Univ. (United States); Harold H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Thermal radiation from objects varies depending on spectral bands

according to Planck's law. By modeling measurements of such radiation as a linear sum of contribution from multiple sources, a thermal scene can be divided into multiple scenes of independent objects that approximate the makeup of the original scene. We pose the scene composition as an inverse blind source separation problem, where multiple spectral images are used to improve temperature resolution of the estimated scene. Numerical simulations along with real images from three bands (SWIR, MWIR, and LWIR) suggest the feasibility of selective source removal and radiative spectral extrapolation, which can lead to thermal image enhancement. Practical issues related to the use of multiple spectral images (such as image registration and choice of sensing bands) are also discussed.

9496-19, Session 5

Auxiliary function approach to independent component analysis and independent vector analysis (Unsupervised Learning ICA Award Invited Presentation)

(Invited Paper)

Nobutaka Ono, National Institute of Informatics (Japan)

In this paper, we present a fast and stable learning rule for independent component analysis (ICA) and independent vector analysis (IVA) for super-Gaussian sources based on auxiliary function method, which is an optimization technique and can be considered as Expectation Maximization (EM) algorithm. In the auxiliary function method, an auxiliary function, which is like a Q function in EM algorithm, is introduced. Then, instead of directly minimizing an objective function, the auxiliary function is iteratively minimized. We show that for a quadratic function can be a good auxiliary function, which is minimized in a closed form, for a contrast function of ICA or IVA when sources are assumed to follow super Gaussian distributions. The derived algorithm consists of two alternative updates: 1) weighted covariance matrix updates and 2) demixing matrix updates, which include no tuning parameters such as a step size in gradient descent method. The monotonic decrease of the objective function at each update is guaranteed. The experimental evaluation shows that the derived update rules yield faster convergence and better results than natural gradient updates. A fast implementation on a mobile phone is also presented.

9496-20, Session 5

How do artificial neural networks (ANNs) compare to partial least squares (PLS) for spectral interference correction in optical emission spectrometry?

Z. Li, X. Zhang, Vassili Karanassios, Univ. of Waterloo (Canada)

Regardless of the number of the groove density of the grating used in a spectrometer for optical emission measurements, in atomic emission spectrometry, a spectrometer with a relatively long focal length (e.g., 0.5 m to 0.75 m) is required in order to obtain the desired resolution (e.g., in the pico-meter regime). Resolving power is a quantitative measure of resolution. Relatively high resolving power is required to address (but not completely eliminate) spectral overlaps (often called spectral interference effects). 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 of a challenge as the focal length of the spectrometer is decreased, for example down to 12-15 cm. Short focal length spectrometers (translating to reduce size and weight) are better suited for portable chemical measurements in the field. Although increasing the number of grooves/mm in gratings 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 additional experimental results (over what previously reported).

9496-21, Session 5

Biomining: bridging the gap between health and security LDA

Jeffrey C. Jenkins, The Catholic Univ. of America (United States); Christopher Frenchi, Christopher Newport Univ. (United States); Charles Sweet, LoftMind, Inc. (United States); Binh Q. Tran, Harold H. Szu, The Catholic Univ. of America (United States)

What is the difference between identifying a person and identifying a disease? Aside from the sensors, motivation, and features used to make inference, not much. Machine Learning (ML) techniques have been successfully used to perform Detection, Identification and Recognition (DIR) in both Biometrics and Biomedical sensing, yet a unified rationale for coupling the two data representations has eluded researchers. Drawing from ML fundamentals, we identify a methodology of utilizing Large Data Analysis (LDA) as a bridge between Biometrics and Biomedical wellness. We can leverage features from Biometric sensors and Biomedical sensors to form a combined feature space that can better equip researchers to understand their data. Without knowing intrinsic attribute relationships apriori, we can discover meaningful association rules between data from different devices for an individual or a group of individuals. We may be able to classify disorders from Biometric data and ID an individual from Biomedical device data. Such a system could also discover which sensors are best suited to 'see' biomarkers or biometric features, provided situational and environmental context. We assess the EEG as a hybrid system where we establish a foundation of Biomining and demonstrate how learnable libraries can emerge without human interaction through ML techniques in a cloud based environment.

9496-22, Session PThu

Detection of cardiac activity changes from human speech

Jaromir Tovarek, Pavol Partila, Miroslav Voznak, Martin Mikulec, Miralem Mehic, V?B-Technical Univ. of Ostrava (Czech Republic)

Impact of changes in blood pressure and pulse from human speech is disclosed in this article. The symptoms of increased physical activity are pulse, systolic and diastolic pressure. There are many methods of measuring and indicating these parameters. The measurements must be carried out using devices which are not used in everyday life. In most cases, the measurement of blood pressure and pulse following health problems or other adverse feelings. Nowadays, research teams are trying to design and implement modern methods in ordinary human activities. The main objective of the proposal is to reduce the delay between detecting the adverse pressure and to the mentioned warning signs and feelings. Common and frequent activity of man is speaking, while it is known that the function of the vocal tract can be affected by the change in heart activity. Therefore, it can be a useful parameter for detecting physiological changes. A method for detecting human physiological changes by speech processing and artificial neural network classification is described in this article. The pulse and blood pressure changes was induced by physical exercises in this experiment. The set of measured subjects was formed by ten healthy volunteers of both sexes. None of the subjects was a professional athlete. The process of the experiment was divided into phases before, during and after physical training. Pulse, systolic, diastolic pressure was measured and voice activity was recorded after each of them. The results of this experiment describe a method for detecting increased cardiac activity from human speech using artificial neural network.

9496-23, Session PThu

FPGA-based realtime blind source separation with principal component analysis

Matthew Wilson, Uwe Meyer-Baese, Florida State Univ. (United States)

Principal component analysis (PCA) is a popular technique in reducing the dimension of a large data set so that more informed conclusions can be made about the relationship between the values in the data set. Blind source separation (BSS) is one of the many applications of PCA, where it is used to separate linearly mixed signals into their source signals. This project attempts to implement a BSS system in hardware. Due to unique characteristics of hardware implementation, the Generalized Hebbian Algorithm (GHA), a learning network model, is used. The FPGA used to compile and test the system is the Altera Cyclone III EP3C120F780I7

9496-24, Session PThu

Independent component analysis algorithm FPGA design to perform real-time blind source separation

Uwe Meyer-Baese, Crispin Odom, Florida State Univ. (United States); Guillermo Botella, Univ. Complutense de Madrid (Spain); Anke Meyer-Baese, Florida State Univ. (United States)

The conditions that arise in the Cocktail Party Problem prevail across many fields creating a need for of Blind Source Separation. The need for BSS has become prevalent in several fields of work. These fields include array processing, communications, medical signal processing, and speech processing, wireless communication, audio, acoustics and biomedical engineering. The concept of the cocktail party problem and BSS led to the development of Independent Component Analysis (ICA) algorithms. ICA proves useful for applications needing real time signal processing. The goal of this thesis was to perform an extensive study on ability and efficiency of Independent Component Analysis algorithms to perform blind source separation on mixed signals in software and implementation in hardware with a Field Programmable Gate Array (FPGA). The Algebraic ICA (A-ICA), Fast ICA, and Equivariant Adaptive Separation via Independence (EASI) ICA were examined and compared. The best algorithm required the least complexity and fewest resources while effectively separating mixed sources. The best algorithm was the EASI algorithm. The EASI ICA was implemented on hardware with Field Programmable Gate Arrays (FPGA) to perform and analyze its performance in real time.

9496-30, Session 6

Sampling theorems for structured signals *(Invited Paper)*

Joel A. Tropp, California Institute of Technology (United States)

For over 40 years, researchers have studied methods for identifying a structured signal from linear measurements using convex optimization. The appropriate optimization problem depends on a priori information about the type of structure that is latent in the signal. Familiar examples include l1-norm minimization for recovering sparse signals and Schatten 1-norm minimization for recovering low-rank matrices, but there are many others.

Extensive empirical work suggests that there is a phase transition in the number of measurements that are needed to recover a specific signal using convex optimization. This talk summarizes ideas from the last five years that allow us to compute the precise number of measurements required to identify a given type of structure. These results can be interpreted as sampling theorems for structured signals. We also discuss some recent research that validates the theoretical predictions in more applied settings.

9496-32, Session 7

Quantitative real-time analysis of collective cancer invasion and dissemination *(Invited Paper)*

Andrew Ewald, Johns Hopkins Univ. (United States)

No Abstract Available

9496-34, Session 8

3D printed bionic nano-materials *(Invited Paper)*

Michael C. McAlpine, Princeton Univ. (United States)

The ability to three-dimensionally interweave biology with nanomaterials could enable the creation of bionic devices possessing unique geometries, properties, and functionalities. The development of methods for interfacing high performance devices with biology could yield breakthroughs in regenerative medicine, smart prosthetics, and human-machine interfaces. Yet, most high quality inorganic materials: 1) are two dimensional, 2) are hard and brittle, and 3) require high crystallization temperatures for maximally efficient performance. These properties render the corresponding devices incompatible with biology, which is: 1) three dimensional, 2) soft, flexible, and stretchable, and 3) temperature sensitive. These dichotomies are solved by: 1) using 3D scanning and printing for hierarchical, interwoven, multiscale material and device architectures, 2) using nanotechnology as an enabling route for overcoming mechanical discrepancies while revealing new effects due to size scaling, and 3) separating the materials synthesis and 3D printed assembly steps to enable conformal integration of high quality materials with biology. The coupling of 3D printing, novel nanomaterial properties, and 'living' platforms may enable next-generation nano-bio interfaces and 3D printed bionic nanodevices.

9496-27, Session 9

Hardware enhance of brain computer interface *(Invited Paper)*

Jerry Wu, J2 Universe LLC (United States); Harold H. Szu, The Catholic Univ. of America (United States)

The history of brain–computer interfaces (BCIs) starts with Hans Berger's discovery of the electrical activity of the human brain and the development of electroencephalography (EEG). Recent years, BCI researches are focused on Invasive, Partially invasive, and Non-invasive BCI. Furthermore, EEG can be also applied to telepathic communication which could provide the basis for brain-based communication using imagined speech. It is possible to use ECoG signals to discriminate the vowels and consonants embedded in spoken and in imagined words and apply to military product. In this report, we begin with an example of using high density EEG with high electrode density and analysis the results by using BCIs. The BCIs in this work is enhanced by A field-programmable gate array (FPGA) board with optimized two dimension (2D) image Fast Fourier Transform (FFT) analysis.

9496-28, Session 9

Spatially revolved electroencephalography *(Invited Paper)*

Jerry Wu, J2 Universe LLC (United States); Harold H. Szu, The Catholic Univ. of America (United States)

Electroencephalography (EEG) measures voltage fluctuations resulting from ionic current flows within the neurons of the brain. In practice, EEG refers to the recording of the brain's spontaneous electrical activity over a short period of time, several tens of minutes, as recorded from multiple electrodes placed on the scalp. In order to improve the resolution and the distortion cause by the hair and scalp, large array magnetoencephalography (MEG) systems are introduced. The major challenge is to systematically compare the accuracy of epileptic source localization with high electrode density to that obtained with sparser electrode setups. In this report, we demonstrate a two dimension (2D) image Fast Fourier Transform (FFT) analysis along with utilization of Peano (space-filling) curve to further reduce the hardware requirement for high density EEG and improve the accuracy and performance of the high density EEG analysis.

9496-29, Session 9

Simulated annealing model of acupuncture *(Invited Paper)*

Charles Shang, Baylor College of Medicine (United States); Harold H. Szu, The Catholic Univ. of America (United States)

The growth control singularity model (reviewed in http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2644274/) suggests that acupuncture can cause perturbation around singular points (acupuncture points or acupoints) of the growth control system with effects similar to simulated annealing. Such perturbation can lead to local and/or global optimization of a physiological system by shaking a system from a suboptimal, diseased state to a healthier state. This model can explain many results of randomized controlled trials on acupuncture. In clinical trial, the goal of a treatment is to relieve certain disorder which corresponds to reaching certain local optimum in simulated annealing. The total amount of energy of the system during the annealing process is limited and related to the person's general health and age in the case of acupuncture. The perturbation at singular points can lead a higher local excitation (annealing temperature) for annealing compared to perturbation at non-singular points (placebo control points). Such difference diminishes as the number of perturbed points increases due to the wider distribution of the limited energy. Perturbation at too many points can dissipate the energy below a critical annealing temperature and compromise the optimization.

This model explains the following facts of randomized controlled trials on acupuncture:

1. Well chosen single acupoint treatment for certain disorder can lead to reliable therapeutic effect above placebo

2. When multiple acupoints are used at the same time, the result can be reliable if the patients are relatively healthy and young (i.e. the intended local optimum of the trial is often the same as global optimum) but are usually mixed if the patients are old, frail and have multiple disorders at the same time.

3. As number of acupoints used in a trial increases, the efficacy difference between sham and real acupuncture often diminishes.

It also correctly predicted that the efficacy of acupuncture is inversely correlated to the disease chronicity, severity and patient's age.

This model suggests that acupuncture trial is most likely to show positive efficacy when few, well chosen acupoints are used on relatively healthy, young patients. This is the first biological – physical model of acupuncture which can predict and guide clinical acupuncture research.

9496-36, Session 9

Computational intelligence from AI to BI and NI *(Invited Paper)*

Paul J Werbos, Center for Large-Scale Integration and Optimization of Networks CLION (United States)

No Abstract Available

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9497-2, Session 1

Color image retrieval and analysis

Chen Gao, Karen Panetta, Tufts Univ. (United States); Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

Color is an essential property human perceived. Color analysis is pivotal in image and video retrieval, food quality evaluation, paint color search, and other consumer applications. In this paper, a new color space model LUXV which is consistent with human vision is proposed. In addition, a new non-reference colorfulness measure is presented. This new measure saved each color as a global index offline. Therefore, when a new color is added for retrieval, there is no need to calculate distances to all candidate colors in the database as the traditional methods do. The experimental results show that using the proposed colorfulness measure on the LUXV color space can effectively and efficiently retrieval colors and images with the most similar colors.

9497-3, Session 1

A nonparametric hypothesis testing approach to wavelet domain image fusion

Stephen P. DelMarco, BAE Systems (United States)

Data fusion can be used to generate high quality data from multiple, degraded data sets by appropriately extracting and combining “good” information from each degraded set. In particular for image fusion, it may be used for image denoising, deblurring, or pixel dropout compensation. Image fusion is often performed in an image transform domain. In transform domain fusion approaches, transform coefficients from multiple images may be combined in various ways to produce an improved transform coefficient set. The fused transform data is inverted to produce the fused image. In this paper we formulate a general approach to image fusion in the wavelet domain. The proposed approach exploits context information, through application of nonparametric statistical hypothesis testing. The use of statistical hypothesis testing places the fusion on a theoretically sound and principled basis, and leads to improved fusion performance. Furthermore, use of statistical wavelet coefficient information in a neighborhood of the test coefficient more fully exploits the available context information. In this paper we first formulate the fusion approach. We then present numerical image data fusion results using a sampling of imagery from a public domain image database. We compare fusion performance of the proposed approach with performance of other standard wavelet-domain fusion approaches, and show a performance improvement when using the proposed approach.

9497-4, Session 1

Improved patch-based learning for image deblurring

Dong Bo, Haopeng Zhang, Zhiguo Jiang, Beihang Univ. (China)

Images have been widely applied in aerospace, military surveillance, road transportation monitor, medical care, etc. However, the blurring usually occurs when capturing images, making troubles for the tasks of feature extraction, object identification, image analysis, etc. Thus, restoration techniques are needed to improve the quality of blurred images to meet the realistic requirements. Most recent image deblurring methods only use valid information found in the input image as the clue to fill the deblurring region. These methods usually have the defects of insufficient prior information and relatively poor adaptively?In this paper, we proposed a non-blind restoration algorithm based on learning patch likelihoods. Patch-based method not only uses the valid information of the input image itself?but also utilizes the prior information of the sample images to improve the adaptively?However the cost function of this method is quite time-consuming, and the method may also produce ringing artifacts. Focusing on these problems, we analyzed and improved the non-blind restoration algorithm based on learning patch likelihoods. In order to enhance time-consuming, we considered the effect of the Gaussian mixture model with different weight and normalize the weight values, which can optimize the cost function. To solve the ringing artifacts, a ringing artifacts post processing method was proposed. Extensive experiments have been performed, as well as comparison with state-of-the-arts, including Richardson-Lucy filter, TV model, and Bregman iteration. Four image quality measures are used to evaluate the performance of image deblurring. Experimental results verify that our method can effectively reduce the execution time, suppress the ringing effectively, and keep the quality of image deblurring.

9497-5, Session 1

Intensity and resolution enhancement of local regions for object detection and tracking in wide area surveillance

Evan Krieger, Vijayan K. Asari, Saibabu Arigela, Theus Aspiras, Univ. of Dayton (United States)

Object tracking in wide area motion imagery is a complex problem that consists of object detection and target tracking over time. The object detection portion is well suited for human analysts. An analyst has the ability to focus on the object of interest and ignore unneeded data. The human eye also has the ability to deal with high dynamic range lighting situations. Human have a duplex retina which allows for good visual discrimination in all lighting conditions. The eye also uses the pupil to adapt to local lighting conditions. A human analyst can also intelligently use additional tools to magnify the object of interest. The use of a magnification tool allows the analyst to see additional details of the object for more accurate tracking. A computer vision solution for object tracking has the potential to be a much faster and efficient solution; however it faces challenges that do not affect the human analyst. The imagery captured for computer analysis has a limited dynamic lighting range due to the globally set exposure of the camera. This results in overexposed and underexposed regions where there is a loss or suppression of data. In addition, wide area motion imagery is typically taken over huge areas where the objects of interest, like cars and people, have a very low spatial resolution. In WAMI data the object’s spatial resolution chosen to be as minimal as possible for recognition in order to have the largest possible expanse of the data captured. The proposed solution for improving computer vision object tracking results is to mimic the abilities of a human analyst. The proposed solution simulates three aspects of human object detection. First, the focus of a human analyst is emulated by only doing work on the local object search area. By focusing the processing efforts on only the local search area the computation requirements are decreased. Second, the solution proposed is that an intensity enhancement process should be done on the local area in order to improve the visual quality of image. An intensity enhancement process can improve the detection by improving the contrast in overexposed and underexposed regions. Finally, the proposed solution includes locally increasing the spatial resolution of the search area. By using a super resolved search area, the features can be better extracted and matched to the object of interest. A quantitative evaluation is performed to show tracking improvement using the proposed method. The testing is done first to find which of three enhancement methods has the most benefit for the tracking process. The local enhancement and super resolution process is then evaluated using the highest performing enhancement method.

The process is evaluated by comparing the resulting object locations found by the tracker to the known object locations. The three databases, each grayscale sequences that were taken from aircrafts, used for these evaluations include the Columbus Large Image Format database, the Blue Devil database, and the Sussex database.

9497-6, Session 1

Image restoration using 2D autoregressive texture model and structure curve construction

Viacheslav V. Voronin, Vladimir I. Marchuk, Alexander I. Sherstobitov, Don State Technical Univ. (Russian Federation); Ilya Svirin, CJSC "Nordavind" (Russian Federation); Sos S. Agaian, The Univ. of Texas at San Antonio (United States); Karen O. Egiazarian, Tampere Univ. of Technology (Finland)

Image inpainting, and, in general, image reconstruction are very important problems in image processing. An ultimate goal of image inpainting is to restore a missing (damaged) area of "empty" pixels regions in a visually plausible manner using information outside of the damaged domain. An automatic restoration of damaged or missing pixels is an image reconstruction problem coming from many practical multimedia applications, such as retouching of digital photographs, restoring images, image coding, computer vision, etc. In this work we use geometric image model. In this case any image can be divided into several areas such as texture regions, non texture and edges on the local geometric features and different spatial configuration. In this paper an image inpainting approach based on the construction of a composite curve for the restoration of the edges of objects in an image using the concepts of parametric and geometric continuity is presented. It is shown that this approach allows to restore the curved edges and provide more flexibility for curve design in damaged image by interpolating the boundaries of objects by cubic splines. After edge restoration stage, a texture restoration using 2D autoregressive texture model is carried out. In this paper we propose an algorithm to represent and reproduce texture regions based on the estimation of spatial autoregressive processes. The image intensity is locally modeled by a first spatial autoregressive model with support in a strongly causal prediction region on the plane. Model parameters are estimated by Yule-Walker method. Several examples considered in this paper show the effectiveness of the proposed approach for large objects removal as well as recovery of small regions on several test images.

9497-8, Session 1

European activities in civil applications of drones: an overview of remotely piloted aircraft systems (RPAS) *(Invited Paper)*

Reiner Creutzburg, Fachhochschule Brandenburg (Germany)

No Abstract Available

9497-10, Session 1

A 3D cluster-driven trilateral filter for speckle reduction in ultrasound images

Zhilong Hu, Jinshan Tang, Michigan Technological Univ. (United States)

In this paper, we propose a cluster-driven bilateral filter for speckle reduction in 3D ultrasound images. The proposed filter used a cluster-based weighting. The introduction of clustering method increases the time cost of bilaterial filter and thus we propose graphic processing units (GPU) technique to reduce the cost. A GPU framework for 3D cluster-driven bilateral filter is presented in this paper. The experimental results show significant improvement on processing efficiency after GPU technique is applied.

9497-11, Session 1

Image enhancement using hierarchical Bayesian image expansion super resolution

Timothy Whitney, Jeremy Straub, Ronald Marsh, Univ. of North Dakota (United States)

Super-resolution is term for a collection of image enhancement techniques that use one or more low-resolution input images to produce an enhanced (higher resolution) output image. Multiframe super resolution takes in a set of low resolution (LR) images of a target object and, by combining the information from each image, calculates subpixel values that are used to build a high resolution (HR) output image. Many multiframe super resolution implementations exist, including Iterative Back Projections, Bayesian, Projection onto Convex Sets and Iterative Adaptive Filtering. These methods conform to a similar paradigm: the super resolution algorithm is run once using a set of multiple LR input images to produce one HR image. This paper presents and discusses the results of a technique, called hierarchical super-resolution, where the super resolution algorithm is run multiple times, using a larger set of LR input images.

This approach takes a^n input images (where a is the number of images in a hierarchy layer and n is the number of layers in the hierarchy) and performs super resolution on each initial group of five. The results of this are then used as inputs for the next higher layer of super resolution. This process is repeated n times, until a final HR image is produced. In many cases, this hierarchical technique is able to produce a better quality image than the traditional single run super-resolution approach. This hierarchical method allows existing super resolution algorithms to be used to further enhance the quality of images, without requiring the modification of the underlying super resolution algorithm. This makes the hierarchical approach, prospectively, easily interoperable with existing super-resolution algorithms. Potential uses for hierarchical super-resolution exist in computer vision, robotics, healthcare and any application in which higher than capture-level image quality is essential.

9497-12, Session 2

Encryption for confidentiality of the network and influence of this to the quality of streaming video through network

Lukas Sevcik, Dominik Uhrin, Jaroslav Frnda, Miroslav Voznak, V?B-Technical Univ. of Ostrava (Czech Republic); Homer Toral Cruz, University of Quintana Roo (Mexico); Martin Mikulec, V?B-Technical Univ. of Ostrava (Czech Republic); Sergej Jakovlev, Klaipeda Univ. (Lithuania)

The recently growing interest in real-time service (like audio and video), transfer through packet networks based on IP protocol. It leads to analyses of these services, and their behavior is in such networks becoming more intensive. Video has become the majority part of all data traffic sent via IP networks. In general, a video service is one-way service (except e.g. video calls) so network delay is not such an important factor as it in voice service. Dominant network factors that influence the final video quality are especially packet loss, delay variation and the capacity of the transmission links. Analysis of video quality concentrates on the resistance of video codecs to packet loss in the network, which causes artefacts in the video.

IPsec provides confidentiality in terms of safety, integrity and non-repudiation (using HMAC-SHA1 and 3DES encryption for confidentiality and

AES in CBC mode) with an authentication header and ESP (Encapsulating Security Payload).

OpenVPN is a full featured secure network tunneling VPN software solution. OpenVPN is tightly bound to the OpenSSL library and derives much of its crypto capabilities from it. OpenVPN supports conventional encryption using a pre-shared secret key or public key security (SSL/TLS mode). OpenVPN also supports unencrypted TCP/UDP tunnels.

MPLS VPN is a technology that allows a Service Provider to have complete control over parameters that are critical to offering its customers service guarantees about bandwidth throughputs, latencies and availability. The technology enables secure Virtual Private Networks (VPN) to be built and allows scalability.

9497-14, Session 2

On a simulation study of cyber-attacks on vehicle-to-infrastructure communication in intelligent transportation system

Nnanna N. Ekedebe, Wei Yu, Towson Univ. (United States); Houbing Song, West Virginia Univ. (United States); Chao Lu, Towson Univ. (United States)

The Intelligent Transportation System (ITS) is one type of cyber-physical system that aims to provide efficient/low latency, effective, reliable, and safe driving experiences with minimal congestion and effective traffic flow management. To achieve this goal, ITS applications such as inter-vehicle communications (IVC), vehicle-to-vehicle (V2V), and vehicle-to-infrastructure (V2I) should work synergistically. In an ITS, security, privacy, and safety concerns are some of the major challenges, militating against the full adoption of ITS technology by concerned stakeholders in the real-world, thereby obviating the realization of these wonderful benefits. Because safety is a fundamental requirement for ITS, security, and privacy preserving mechanisms must not vitiate safety, meaning that all security and privacy enhancing mechanisms must complement or improve safety rather than endanger it.

As a result of the ITS's reliance on wireless connectivity, V2V, and V2I communications are, consequently made vulnerable to cyber-attacks, posing message deletion, modification, forgery, and replay attacks by an adversary. Because of the safety nature of VANET (Vehicular Ad Hoc Network) messages, these possible compromises must not be overlooked with impunity. In this paper, using V2I communication and real-world transportation dataset, we evaluate the consequences of cyber-attacks (e.g. attacks against service availability by jamming the communication channel and other ways) on a typical VANET system. In this way, we can have a better understanding on the importance of ensuring adequate security respecting safety VANET applications before full real-world deployment of this promising technology. Our experimental results show that cyber-threats (such as ones against service availability) can adversely affect traffic efficiency and safety evidence by exacerbated travel time, fuel consumed, and other evaluated performance metrics as the communication network is compromised. In addition, we discuss a framework to make ITS secure and resilient against cyber-attacks.

9497-15, Session 2

Transform domain steganography with blind source separation

Ismail I. Jouny, Lafayette College (United States)

This paper applies blind source separation and independent component analysis for images that may contain mixtures of text, audio, or other images for steganography purposes. The paper focuses on separating mixtures in the transform domain such as 2-D Fourier domain or the Wavelet domain. The study addresses the effectiveness of steganography when using linear mixtures of multimedia components and the ability of standard blind sources separation techniques to discern hidden multimedia messages. The transform domain mixture is an added layer of secrecy and security that demands additional computational cost and hardware. The paper uses standard ICA or separation schemes, and the mixing process is linear using real valued matrices. Mixing in the space, frequency, and wavelet (scale) domains is compared. Effectiveness is measured using mean square error rate between original and recovered images, and effectiveness of the steganography scheme is also measured using the mean square error between the original dominant image and the mixture images.

9497-16, Session 2

Information security trades in tactical wireless networks

Michael T. Kurdziel, Harris Corp. (United States) and Rochester Institute of Technology (United States); John A. Alvermann, Harris Corp. (United States)

Wireless networks are now ubiquitous across the tactical environment. They offer unprecedented communications and data access capabilities. However, providing information security to wireless transmissions without impacting performance is a challenge. The information security requirement for each operational scenario presents a large trade space for functionality versus performance. One aspect of this trade space pertains to where information security services are integrated into the protocol stack. This paper will present an overview of the various options that exist and will discuss the advantages and disadvantages of each option.

9497-37, Session 2

A better detection of 2LSB steganography via standard deviation of the extended pairs of values

Omed S. Khalind, Benjamin Aziz, Univ. of Portsmouth (United Kingdom)

This paper proposes a modification to the Extended Pairs of Values (EPoV) method of 2LSB steganalysis. In EPoV, the detection and the length estimation of the hidden message were performed in two separate processes as it considered the automated detection process. However, the new proposed method uses the standard deviation of the EPoV to measure the amount of distortion in the stego image made by the embedding process, which is directly proportional with the embedding rate of the 2LSB steganography. It is shown that it can accurately estimate the length of the hidden message and outperform the other methods of the targeted 2LSB steganalysis in the literature. The proposed method is also more consistent with the steganalysis methods in the literature by giving the amount of difference to the expected clean image. The experimental results, based on analysing 3000 never-compressed images, show that the proposed method is more accurate than the current targeted 2LSB steganalysis methods for low embedding rates.

9497-38, Session 2

Environmental network monitoring by smart devices using sparse recovery algorithm

Joon Young Lee, Arizona State Univ. (United States)

Environment network monitoring has been investigated in Phoenix, Arizona, United States for a recent time period. In this study, I introduce a sparse recovery algorithm and apply it to estimation of environmental network, which can be gathered by smart devices. First, I describe that it is applicable to the environment network estimation. Relying on the Google for important data, I built the environment network data. The mathematical formulation

is shown and the l1-optimization is formulated for the proposed method. By several validity tests, I show that it meets the compressible requirements and l1-optimization enables environment network estimation to be effective in that the total measurements of registered devices can be reduced down by approximately 31%. I provide visualizations of environment network in Phoenix, Arizona, US by quarters of 2014.

9497-17, Session 3

Capon-based single snapshot DOA estimation in monostatic MIMO radar

Aboulnasr Hassanien, Moeness G. Amin, Yimin D. Zhang, Fauzia Ahmad, Villanova Univ. (United States)

We consider the problem of single snapshot direction-of-arrival (DOA) estimation of multiple sources in monostatic multiple-input multiple-output (MIMO) radar. After performing pulse compression, the data associated with each Doppler-range bin within each radar pulse is represented by a single snapshot. When a single snapshot is used, the covariance matrix of the data becomes rank deficient and, therefore, does not enable applying high-resolution DOA estimation techniques. On the other hand, low-resolution techniques, such as the conventional beamformer, suffer from biased estimation and fail to resolve closely spaced sources. In this paper, we propose a new Capon-based method for DOA estimation in MIMO radar using one radar pulse. Assuming that the general angular locations of the sources are known a priori to be located within a certain spatial sector, we employ multiple transmit beams to focus the transmit energy of multiple orthogonal waveforms within the desired sector. The transmit weight vectors are carefully designed such that they have the same transmit power distribution pattern. As compared to the standard MIMO radar concept, the proposed approach enable transmitting a number of orthogonal waveforms that is much higher than the number of transmit antennas. By using matched-filtering at the receiver, the data associated with different beams are extracted and stacked together to form a virtual data block. The number of virtual snapshots is equal to the number of transmit beams. By choosing the number of transmit beams to be larger than the number of receive elements, it becomes possible to form a full-rank sample covariance matrix. The Capon beamformer concept is then applied to estimate the DOAs of the targets of interest. The proposed method is shown to have improved DOA estimation performance as compared to conventional single snapshot DOA estimation methods. Simulation results are provided that illustrate the superiority of the proposed method over existing techniques.

9497-18, Session 3

Building occupant and asset localization and tracking using visible light communication

Kofi Nyarko, Samuel Mbugua, Christian Emiyah, Morgan State Univ. (United States)

LED lighting is becoming more and more ubiquitous within new commercial building constructions and retrofits due to their well documented merits of energy efficiency, environmental friendliness, and reduced cost of operation compared to incandescent and fluorescent lighting. Besides these benefits, LED lighting provides an opportunity for performing visible lighting communication (VLC). This research demonstrates how inexpensive commercial off-the-shelf lighting components and microcontrollers can be used to construct a whole building solution for occupant and asset localization and tracking through VLC. Through the modulation of the emitted light from mesh networked LED luminaires, the location of a “smart” tag can be determined and relayed to a central database. This paper describes the implementation of the VLC enabled LED luminaires, in addition to the customized infrared synchronization protocol, which enabled inexpensive single frequency diodes to be time division multiplexed to avoid packet collisions. Specifically, high lumen LEDS are modulated using differential pulse position modulation to communicate with an asset or occupant tag. The tag senses unique identifiers sent by each module in addition to relative intensity readings from luminaires to determine location. Luminaires use a communication chain approach (token message passing) to regulation packet transmission. This approach also serves as the basis for an IR based mesh networking and distributed computing protocol that is suitable for eliminating any additional building infrastructure besides power. The significance of this research is to demonstrate how new constructions and building retrofits can easily and affordably achieve whole building localization and tracking for intelligent building operations, asset management, occupant safety and building security.

9497-19, Session 3

Experimental studies of high-accuracy RFID localization with channel impairments

Eric Pauls, Yimin D. Zhang, Villanova Univ. (United States)

Radio frequency identification (RFID) systems present an incredibly cost-effective and easy-to-implement solution to close-range localization. One of the important applications of a passive RFID system is to determine the reader position through multilateration based on the estimated distances between the reader and multiple distributed reference tags obtained from, e.g., the received signal strength (RSS) readings. In practice, the achievable accuracy of passive RFID reader localization suffers from many factors, such as the distorted RSS reading due to channel impairments in terms of the susceptibility to reader antenna patterns and multipath propagation. Previous studies have shown that the accuracy of passive RFID localization can be significantly increased by properly modeling and compensating for such channel impairments, and sparse signal reconstruction based techniques for reader position estimation were developed. The objective of this paper is to report experimental study results that validate the effectiveness of such approaches for high-accuracy RFID localization. We also examine a number of practical issues arising in the underlying problem that limit the accuracy of reader-tag distance measurements and, therefore, the estimated reader localization. These issues include the variations in tag radiation characteristics for similar tags, effects of tag orientations, and reader RSS quantization and measurement errors. As such, this paper reveals valuable insights of the issues and solutions toward achieving high-accuracy passive RFID localization.

9497-20, Session 3

Efficient target tracking with an ad-hoc networks of omni-directional sensors

Kalin Atanassov, Qualcomm MEMS Technologies, Inc. (United States); William S. Hodgkiss, Univ. of California, San Diego (United States)

Ad-hoc networks of omni-directional sensors provide an efficient means to obtain low-cost, easily deployable and reliable target tracking systems. To remove target position dependency on the target power, a transformation to another coordinate system is introduced that uses power ratios between sensor pairs. Each transform pair defines a circle whose center lies on the line connecting the sensor pair. It can be shown that the problem of sensing target position using power ratios can be adapted to the conventional Kalman filter framework by propagating system and observation noise covariance to the log-ratio space. To validate the proposed methodology, first an analysis is conducted to show that by converting to log-ratio space and thus reducing the number of observed independent parameters, no information about target position is lost. This analysis is done by deriving the CRLBs for the position estimation error in both original and transformed spaces and showing that they are equivalent. Second, to show how the traditional Kalman filter framework performs, a particle filter that works off the transformed coordinates is designed and implemented. The number of particles is selected to be sufficiently large and the result is used as a ground truth to compare with the performance of the Kalman tracker. The comparisons are done for different target movement speeds and sensor density modes. As a result, it is shown that the proposed transformation does not lose information about target position and performs well within a traditional Kalman tracker framework.

9497-21, Session 4

Nonparametric spectrum estimation using generalized coprime sampling

Si Qin, Yimin D. Zhang, Moeness G. Amin, Villanova Univ. (United States)

Spectrum estimation is an important task in civilian and military surveillance applications. While most methods are based on Nyquist sampling, the recent advances of compressive sensing permit sparse sampling to achieve effective spectrum estimation with reduced complexity. Among different sparse sampling strategies, the coprime sampling scheme provides a systematic mechanism to determine sparse sampling patterns for spectrum estimation with a reduced average sampling rate. A coprime sampling approach assumes a pair of coprime integers M and N, and the signals are sampled at the integer multiples of MT and NT, with T denotes a unit sampling interval. It can be shown that, with proper arrangement, coprime sampling with O(M+N) samples can provide a high spectrum resolution with resolution cell inversely proportional to O(MN). In this paper, we propose the generalized coprime sampling schemes to achieve flexible sampling patterns and improved spectrum estimation performance. The problem of nonparametric spectrum estimation is cast as sparse reconstruction of piecewise consecutive spectral entries through the use of Bayesian compressive sensing technique that accounts for clustered dependencies. This method falls into the general class of multi-task Bayesian compressive sensing methods, which yield enhanced capability and improved performance as compared to other sparse reconstruction methods. The required sampling rate is analyzed in this paper, and the effectiveness of the proposed method is verified through simulation examples.

9497-22, Session 4

On an investigation into intelligent transportation system (its) safety, and traffic efficiency applications

Nnanna N. Ekedebe, Nicolas Dolphin, Towson Univ. (United States)

Vehicle-to-X (V2X) (vehicle-to-vehicle [V2V], and vehicle-to-infrastructure [V2I]) communication, used in intelligent transportation system (ITS)/ vehicular ad hoc networks (VANETs), promises improved traffic efficiency, road safety, and provision of infotainment services, etc. However, the levels of these improvements have not been clearly researched and documented especially in realistic environments [1]. Consequently, using field and simulation data, we investigate the safety and traffic efficiency application benefits of V2V communication applications in a realistic scenario. In order to do this, we built a real-world simulation test-bed using real-world/field traffic data of the Maryland (MD)/Washington DC and Virginia (VA) area from July 2012 to December 2012. In addition, we developed an application called incident warning application (IWA) of which IWA-equipped vehicles make use of it to bypass a compound road accident, slippery roadway caused by ice, and reduced visibility as a result of fog; unequipped/classic vehicles are unaware of this and hence suffer adverse effects. On the average, our results show that, indeed, tangible benefits/improvements with respect to travel time (126.78%), average speed (56.12%), fuel consumption (8.05%), CO2 emissions (8.05%) together with other evaluated performance metrics are derivable from V2V communication especially at specific IWA-equipped vehicles penetration rates.

9497-34, Session 4

On the universe's cybernetics duality behavior

Erlan H. Feria, The College of Staten Island of the City Univ. of New York (United States)

On November 10th, 2014 the New York Times reported on major prizes given to scientists (D. Overbye, "Scientists, and Universe's Odd Behavior, Are Recognized with $3 Million Prizes"). Of the contributions leading to these prizes some physicists made use of mathematical dualities that are said to "offer physicists the chance of going around intractable problems of calculation in one system by solving the easier equations in another." This New York Times article also reports that the use of these dualities has become "a cottage industry in physics today." In my paper I will be reviewing work on the universal cybernetics (UC) duality principle, which I discovered in 1978 in control theory while conducting graduate research on cybernetics. UC is the study of control and communications in living and non-living systems. Its duality principle states that, "synergistic physical and mathematical dualities naturally arise in efficient system designs." The UC duality principle uses both mathematical and physical dualities for going around intractable problems of calculation not only in physics but also in control, radar and biological lifespan. The very latest solutions derived by the UC duality principle will be reviewed, inclusive of the nascent linger thermo theory, which has inherently led to a sensible and straightforward relationship between biological lifespan and specific heat-capacity.

9497-35, Session 4

Video sensor calibration by invoking video synopsis approach with external constraint criteria

Sumit Chakravarty, New York Institute of Technology (United States); Sherry Zhu, Nanjing Univ. of Post and Telecommunications (China)

Sensor calibration and comparison in real time factory environment is a challenging task. Not only can we not stop or change the flow of the processes for real time calibration, in most situations we can neither replicate the process exactly there by offloading the calibration or comparison activity from the actual process flow. This process becomes even more challenging for sensor replacement, particularly when considering replacement between sensor which work on different principles. In this paper we target real time sensor calibration of video sensor based on the current tactile sensor, for automatic width estimation for Steel Rolling Mill.

Using the actual rolling mill block diagram and system identification techniques we develop system model to find the open loop input output relationship between sensor input and plant actuator. Our next task is to process captured video of the rolling mills steels plates which is the planned replacement sensor for the steel rolling system. We then present the major aspect of this paper: creation of Synopsis Video, to have efficient and compact representation of video to corroborate with the tactile sensor. By segmenting moving objects and then densely stitching them into background frames, video synopsis provides an efficient way to condense long videos while preserving most important activities. Video synopsis methods rely on suitable constraints to ensure only relevant section of the video are preserved with minimal video size. Typically this is achieved via energy minimization criteria created from the video. In this paper we use external criteria like tactile sensor data to extend of energy minimization formulation and thereby provide better synopsis of the video for our sensor calibration and comparison problem. The temporal and spatial synopsis of the video enable the calibration process to be evaluated efficiently by visual confirmation. Experimental results demonstrate the effectiveness of proposed approach which provides alternative approach to solve to problem of sensor calibration for real-time process applications.

9497-40, Session 4

Emotion recognition from speech: tools and challenges

Abdulbasit Al-Talbani, Harin Sellahewa, Sabah A. Jassim, The Univ. of Buckingham (United Kingdom)

Human emotion recognition from speech is studied frequently for its importance in many applications, e.g. human- computer interaction. There is a wide diversity and non-agreement about the basic emotion or emotion-related states on one hand and about where the emotion related information lies in the speech signal on the other side. These diversities motivate our investigations into the use of Meta-features using PCA extracted from a large number of features that cover wide range of emotion related information. Our focus is investigating the presence of different emotions in the same speech portion. Subsets of Meta-features are fused to increase the performance of the recognition model that adopts the score-based LDC classifier. We shall demonstrate that our scheme outperform the state of the art results when tested on non-prompted databases or acted databases (i.e. when subjects act specific emotions while uttering a sentence). However, the huge gap between accuracy rates achieved on the two types of datasets of speech raises questions about the way emotions modulate the speech. In particular we shall argue that emotion recognition from speech should not be dealt with as a classification problem. We shall demonstrate the presence of a spectrum of different emotions in the same speech portion especially in the non-prompted data sets, which tends to be more "natural" than the acted datasets where the subjects attempt to suppress all but one emotion.

9497-23, Session 5

A modified CMA equalizer for SOQPSK for aeronautical telemetry

Arlene Cole-Rhodes, Morgan State Univ. (United States)

We present the results of using a modified constant modulus algorithm (CMA) to recover a shaped offset quadrature-phase shift keying (SOQPSK)-TG modulated signal, which has been transmitted over an aeronautical channel using the iNET data packet structure, and we investigate its performance in tracking the transmitted data bits. The iNET-packet structure includes data symbols known as the preamble and asynchronous marker (ASM) symbols, which can be used as pilot symbols within each data packet. The CMA equalizer has been widely used for constellations types such as QPSK, which are constant modulus and it has also been shown to be effective for SOQPSK, which a partial response continuous phase modulation (CPM) with a constrained ternary alphabet. The alphabet-matched algorithm (AMA) will be applied to equalize the QPSK symbols which are produced by the SOQPSK detector. In addition as an alternative to center-tap initialization we have used the known data in the packet to compute the minimum mean square error (MMSE) equalizer, and this is used to initialize the CMA +AMA algorithm. Performance evaluation results are presented for SOQPSK from this modified CMA equalizer, and this is compared to the results of using the CMA only equalizer.

9497-36, Session 5

New cognitive detection techniques for multimedia signals

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In this paper we are address two issues regarding cognitive radio spectrum sensing. Spectrum sensing for cognitive radio has been extensively studied in recent past and multiple techniques have been proposed. One such technique is entropy based detection. In entropy based detection we measure the entropy of the received signal after converting it to frequency domain. The logic is that in frequency domain, the entropy of noise (assuming its AWGN) is higher than the signal, thereby enabling us to segment noise from signal by using entropy based threshold. This approach however makes some assumptions which may not be valid. It assumes at a time only one of the two(signal / noise) is present. It further assumes that a given test segment is either a signal or a noise segment. The length of the segment in such a scenario would be fixed /known. These assumptions may be too constraining and we propose alternate method to address the above issues. We use a filtering technique in form of Independent Component Analysis to segment the signal and further use additional techniques like energy weight-age to weigh the components to estimate the signal strength. We test our proposed method for a variety of signals include image, audio and sinusoidal signals. Results show the improvement in performance as well as the availability of new measures as generated from our proposed technique.

9497-39, Session 5

Implementing MANETS in Android based environment using Wi-Fi direct

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Packet loss occurs in real-time voice transmission over Wireless Broadcast Ad-hoc Network which creates disruptions in sound. This paper aims to make a Wireless Ad-hoc connectivity between two Android smartphones by using the Wireless Fidelity (WIFI) Direct Application Programming Interface (API) and apply the Network Codec which in this case is Reed Solomon Code, it is built for the sole purpose of demonstration and reading the data. The network codec is used to encode the data of a music wav file and recover the lost packets if any, packets are dropped deliberately at the transmitter device only to see if the original file can be recovered at the receiver device using the network codec. This resulted in faster transmission of the files due to dropped packets. In the end both files had the original formatted music files but the time factor was noteworthy.

9497-1, Session PTue

Segmentation of textured images based on descriptor's of local approximations

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Filter banks, textons and local descriptors take an image and transform the raw data into a feature space which separates pixels with different texture. This representation is used to segment the image into regions of different texture. Segmentation is a special case of classification, in that each pixel is assigned to a class. In classification, each data point is separate. Problem of textured image segmentation is sufficiently different from the problem of edge detection and gradient calculation. The texture in an image is not a point property and is only detectable for a group of pixels, which means that nearby data points will have descriptors calculated from overlapping areas of the image.

There are two tasks that are being performed by a segmentation algorithm, namely labelling areas of the image as belonging to a particular object or class, and finding the location of the boundary. They are complimentary activities: labelling the pixels will implicitly place a boundary along some

pixels, while choosing the boundary location will implicitly divide the image up into a number of regions. Since each method is implicitly doing the other task as well, the main difference is how the algorithm is constrained. Algorithms that label pixels will specify how many classes there should be or how coherent members of a class should be. Algorithms that label boundaries will specify boundary length and will quantify how strong the edge must be to be considered a boundary.

The challenge is to find a way to combine the border and region information. In paper present original method of segmentation based on the using texture descriptor design on the local approximations (ID-LPA). A texture descriptor ID-LPA constructing as a set of indices of local approximations. Textured image is divided into non-overlapping patches which are transform into a one-dimensional source vectors. These vectors are approximated using local functions of various parameters. Errors of approximation on each of vectors and for the each of approximation function is indexed and forming descriptor. Algorithm of recognition and classification of local areas using NN and SVM classifiers. Researches are present important properties of descriptor ID-LPA: robustness at luminance, contrast, angel of rotate image. Local areas with equal features are unit into alone area and forming segments of texture image. In paper resent results of supervised and unsupervised segmentation base on ID-LPA texture descriptor. The proposed algorithm allows to segment texture images into separate regions based on the solution of particular problems of texture classification with limited volume of learning vocabulary. In paper presented result of texture image segmentation for cases. The results of comparisons of textured images segmentation are present on images database OUTEX. In image database OUTEX are present set of different masks of segments base on which construct composite test texture images. Edge of segments may have different forms: line, curve, circle, circular arc and so on.

9497-9, Session PTue

Investigation of methods to search for the boundaries on the image and their use on lung hardware of methods finding saliency map

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This work aimed to study computationally simple methods of search saliency map object on images. Research in the field map saliency received increasing interest for the use of sophisticated techniques in portable devices. Knowledge of saliency map can increase the speed of many subsequent algorithms and reduce the computational cost. In work presented iterative algorithms for constructing of search saliency map with the possibility gradation level of significance. The search is performed by analysis the boundaries and corners of objects on images and their localization by the threshold decision. Smooth variation of the threshold used to determine the person's attention to the location of objects in the image. The first algorithm is based on an analysis of the number of transitions in the local area. The second algorithm is based on a comparison of the calculated coefficient obtained by the analysis of the boundaries of the local area and the obtained value for the entire image. The third algorithm is based on an analysis of the number of gradients in the local area. The obtained numerical values of effectiveness computationally of simple methods of finding areas of human attention at the analysis of the boundaries of objects on a set of test images. Obtained graphs of speed works algorithms depending on the number of objects and the image size. The paper discusses methods for finding the boundaries of objects in the image and their comparative characteristics based on analysis of test images. The obtained recommendations for the use of simple techniques in practice.

9497-13, Session PTue

Image Encryption by Redirection and Cyclical Shift

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In this paper, we present a novel method for encrypting and decrypting large amounts of data such as 2-D images, both gray-scale and color, without the loss of information using private keys of varying lengths. The proposed method is based on the concept of the tensor representation of image and splitting the two-dimensional discrete Fourier transform by 1-D DFTs of signals from the tensor representation, or transform. The splitting of the transform is accomplished in a three dimension space, namely on the 3-D lattice placed on the torus. Each splitting-signal of the image defines the 2-D DFT along the frequency-points located on the spirals on the torus. Spirals have different form and cover the lattice on the torus in a complex form, which makes them very effective when moving data through the spirals and between them, and data along the spirals. The encryption consists of several iterative applications of the mapping the 3-D torus into the several ones of small sizes, and rotates and moves the data around the spirals on all tori. The encryption results in the image which is uncorrelated. The decryption algorithm uses the encrypted data and processes them in inverse order with an identical number of iterations. The proposed method can be extended to encrypt and decrypt documents as well as other types of digital media. Simulation results of the purposed method are presented to show the performance for image encryption. The comparison of the proposed method with previously used methods of encryption is given.

9497-27, Session PTue

Simulating the performance of switched diversity with post-examining selection

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Switched diversity is a solution to fading channel distortion that uses 2 or more branches to monitor the received signal. The main assumption is that the branches are uncorrelated. Switched diversity uses a switching threshold that is the criterion for an acceptable received signal path. If no acceptable path is chosen, one is chosen randomly, for a traditional switched diversity scheme. This paper will look into a modified hybrid switched/selection scheme proposed in a separate paper [1]. This scheme will help the receiver pick the best path if no acceptable path is chosen, but there will some tradeoff. This paper will also simulate the theoretical results found from the paper as well using MATLAB, thus validating their findings. A LOS analysis will be examined as well. The proposed scheme is called switch and examine combining with post-examining selection (SECps), which is a variant of switch and examine combining (SEC). We will include the findings from [1] for reference.

9497-28, Session PTue

Parsimonious sidelobe control for transmit beamforming in MIMO radar with multidimensional arrays

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Two-dimensional (2D) transmit beamforming is used in multiple-input multiple-output (MIMO) radar to focus the transmitted energy within ceratin desired sector(s) while minimizing the amount of energy wasted in the out-of-sector regions. Recent approaches to designing 2D transmit beamforming achieve sidelobe control by imposing sidlobe constraints in order to upper-bound the worst sidelobe level. The out-of-sector regions are usually approximated by a discrete grid where a sidlobe constraint is

imposed at each point on the grid. The use of fine 2D grid dramatically increases the number of sidelobe constraints resulting in a very high computational burden. On the other hand, the use of a coarse grid results in transmit power leakage within the uncontrolled sidelobes located between the coarse grid points. In this paper, we propose parsimonious formulations to the sidelobe control problem in MIMO radar with multidimensional arrays. We divide the out-of-sector regions into few subregions where the subspace spanned by the steering vectors associated with the spatial directions within a certain subregion is approximated by the effective eigenvectors of the discrete-prolate spheroidal sequences. Then, the sidelobe control is achieved by imposing constraints on the magnitude of the inner product between the 2D transmit beamforming weight vector and the effective eigenvalues. Comparisons between the proposed formulations and previous ones are given in terms of the total number of constraints needed, the associated computational complexity, and the sidelobe levels. Simulation results are provided that show the effectiveness of the proposed method.

9497-29, Session PTue

Quaternion Fourier transform-based prediction of coding region in DNA sequences

Artyom M. Grigoryan, Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

DNA or Deoxyribonucleic Acid, which is a double stranded structure made up of four nucleotides -Adenine, Cytosine, Guanine and Thymine, consists of inter-genic regions and is found inside a nucleus of the cell [1,2]. The genes are divided into small protein coding regions known as exons and non-coding spacers known introns. The base sequences in the protein-coding regions of DNA molecules have a period-3 component and this property is used to indicate the gene location, by using a band pass digital filter or computing the discrete Fourier transform. The ability of the discrete Fourier transform to identify the accurate boundaries of the 3-period signal is limited by its requirement of chosen window size over which the spectrum is calculated. In this paper, we present a novel method for prediction of coding region in the DNA sequences, which is based on the presentation of sequences in the quaternion algebra. We choose the quaternion Fourier transform because it is well-suited for four-dimension data and allows us to process all four components or dimensions simultaneously, and it captures the inherent correlation between the components [3,4]. Experimental results show that the proposed method with the representation of nucleotide with quaternion numbers instead of four independent indicator sequences together with the Fourier transform is highly effective in identifying the approximate locations of coding regions. The sufficiencies of the proposed method of prediction of coding regions and comparison with the known methods are described.

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9497-30, Session PTue

Inpainting for videos with dynamic objects using texture and structure reconstruction

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Recently, applications of video processing and analysis have got a lot attention in field of computer vision. Video inpainting refers to a field of computer vision that aims to remove objects or restore missing or tainted regions present in a video sequence. This paper describes a novel inpainting approach for removing marked dynamic objects from videos captured with a static camera, so long as the objects occlude parts of the scene with a static background. Proposed approach allow to remove objects or restore missing or tainted regions present in a video sequence by utilizing spatial and temporal information from neighboring scenes. The algorithm iteratively performs following operations: achieve frame; update the scene model; update positions of moving objects (this step use the condensation algorithm); replace parts of the frame occupied by the objects marked for remove with use of a background model. As a possible model of background we considered running average, codebook and some others. In this paper, we extend an image inpainting algorithm based texture and structure reconstruction by incorporating an improved strategy for video. An image inpainting approach based on the construction of a composite curve for the restoration of the edges of objects in a frame using the concepts of parametric and geometric continuity is presented. It is shown that this approach allows to restore the curved edges and provide more flexibility for curve design in damaged frame by interpolating the boundaries of objects by cubic splines. After edge restoration stage, a texture reconstruction using patch-based method is carried out. Overview of this step is as follows: we fill-in a static background in the damaged frames by the available temporal information in undamaged frames. This leads to a hole that is common to all the frames which cannot be filled-in temporally. Each damaged frame filled using priority based spatial filling-in scheme is then used to get a best matching for a height priority location. This best match is then copied as in image inpainting. We demonstrate the performance of a new approach via several examples, showing the effectiveness of our algorithm and compared with state-of-the-art video inpainting methods.

9497-31, Session PTue

Assessment of heart rate variability based on mobile device for planning physical activity

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The up-to-date trend of mobile devices using has become the solution to their challenges medical electronic equipment associated with automatic analysis of biomedical information to assess physiological parameters of the body, information support diagnostic decisions of the physician and automatically diagnose pathological changes of the human condition. The greatest social significance has the task of assessing the state of the cardiovascular system, where the key role is played by electrocardiogram (ECG), representing record observed on the body surface projections of the volumetric electrical processes in the heart. ECG carries information about the current state of the cardiovascular system, and pathological changes in the heart. A promising way of ECG analysis is the assessment of heart rate variability. Mathematical processing of heart rate variability allows to obtain a set of mathematical and statistical characteristics. These characteristics of heart rhythm are used in the solution of research tasks for study of physiological changes that determine changes in the functional state of the subject. For practical purposes it is enough to have 2-3 measure, integral reflecting the functional state of a person and determine his valid physical activity. The advent of mobile devices made possible the calculation and measurement of heart rate variability in real-time that allow us to plan and to adjust the physical activity of the person.

9497-32, Session PTue

Network synchronization for secure mobile communication

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For the safe and secure communication for the air transportation systems, this paper proposes an robust adaptive high-gain fuzzy frequency observer design scheme and its application to network synchronization and secure communication. It is assumed that their states are immeasurable and their parameters are unknown. The structure of the proposed robust adaptive high-gain fuzzy fre-quency observer is represented by Takagi–Sugeno fuzzy model and has the integrator of the es-timation error. It improves the performance of high-gain observer and makes the proposed ob-server robust against noisy measurements, uncertainties and parameter perturbations as well. Us-ing Lyapunov stability theory, an adaptive law is derived to estimate the unknown parameters and the stability of the proposed observer is analyzed. Some result of network synchronization and secure communication of chaotic systems is given to present the validity of theoretical deri-vations and the performance of the proposed high-gain fuzzy frequency observer as an applica-tion.

The proposed observer is taken as an application to secure communication. In secure communi-cation, observers are used as receivers. The chaotic signal of the transmitter including any infor-mation signal is sent to the receiver and the information signal is recovered by the proposed ob-server scheme. Note that there needs time interval from start driving to load the information sig-nal to the chaotic signal of the transmitter since the receiver that has the proposed scheme syn-chronizes the chaotic signal of the transmitter first and then the driven chaotic receiver recovers the information. With the proposed observer, the asymptotic synchronization of chaotic systems was achieved and the secure communication of chaotic systems was succeeded.

Chaotic systems have been researched and known to exhibit complex dynamical behavior in the past two decades. The interest in chaotic systems lies on nonstandard control problems including stabilization, synchronization and chaotic model following control since they have unpredictable behavior, and extreme sensitivity to initial conditions as well as parameter variation. It is well-known that synchronization of two chaotic dynamical systems is one of the most important ap-plications of chaos, and many researches have been proposed to achieve synchronization with exactly known or uncertain conditions. In some applications such as secure communication, chaos synchronization has been studied extensively and valuable results have been found, since chaotic signals can hide information efficiently and securely. Transmitting messages masked by chaotic signals or modulated by chaotic systems were studied as a form of secure communication.

The idea of chaotic masking is to directly add the message (information signal) in a noise-like chaotic signal at the transmitter, while chaotic modulation is done by injecting the message into a chaotic system as spread-spectrum transmission. Then, a coherent detector and some signal pro-cessing is thus employed to recover the information signal from the received signal at the receiver. In order to recover it at the receiver, the receiver should synchronize with the transmitter. Most approaches have been developed based on either control or observer as an application for chaotic synchronization.

Observer design has been a very active field during the last few decades and has turned out to be much more difficult than the control problem, since states are partially or fully unavailable in many practical control problems; the state variables are not accessible for direct connections or, sensing devices or transducers are not available or very expensive. In such cases, observer based control schemes should be designed to generate the estimates of states. Many researches on ob-server design for nonlinear systems are carried out based on fuzzy models. As the structure of fuzzy models, Takagi–Sugeno (T–S) fuzzy model is widely accepted as a powerful tool for de-sign and analysis of fuzzy control systems.

Adaptive schemes for nonlinear systems that incorporate fuzzy systems have been enormously popular. The technique, known as a high-gain observer, is to design the observer gain that makes the observer robust against model uncertainties in nonlinear functions. Hence, it works for a wide class of nonlinear systems. However, high gains may excite hidden dynamics and amplify meas-urement noise: large oscillation in the transient response and sensitivity to measurement noise. Thus, a high-gain observer could not be applicable in practice. In order to overcome such a prob-lem, several researchers have successfully designed sliding-mode approach to construct observers that are highly robust with respect to noise in the input of the system. However, it turned out that the corresponding stability analysis could not be directly applied to situations that present output noise.

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9498-1, Session 1

An asset valuation approach using fuzzy logic

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Organisations that own operational networks have many networked assets to support daily business. The business operations are supported by various computer network services, which are in turn supported by the various assets that make up an operational network. Within organisations, some operations are more important than others. Similarly, some services are more important to an operation than others. Assets that support a service also have different levels of importance in support of the service, and therefore operation. For meaningful decision support on the assets and services, network defenders need to know the values of their assets and services. Unfortunately, there is no easy way of knowing or determining asset values of networked assets, and no universally recognised approach to asset valuation exists. Proprietary and published approaches, mostly in risk analysis, tend to assume values whose significance may be hard to justify in practice.

Fortunately, experienced computer security experts can give intuitive guidance on the relative importance of network assets in operational networks. Such experiential knowledge, though unquantifiable through classical relational mathematics, can be generally effective in assigning relative values to assets. In this work, we propose to capitalise on this expertise by combining asset attribute factors with expert and experiential knowledge about the assets to determine their values. We exploit the mathematical theory of fuzzy logic that can be used to model and quantify human expertise and experiential knowledge. We define rules about asset interactions within an operational network and model linguistic declarations about assets and their functions in an operational network that knowledge and expertise to intuitively assign values to assets. Our approach starts by modeling experts' experiential knowledge about assets and their properties as fuzzy variables. Then we use a fuzzy inference system to translate that knowledge into an asset value. We apply our approach to network scenarios and show its potential usefulness to complex networks. Our results show asset values that are a close match with what an experienced expert would infer local asset values to be.

9498-2, Session 1

Reliable sources and uncertain decisions in multisensor systems

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Conflict among information sources is a feature of fused multisource and multisensor systems. Accordingly, the subject of conflict resolution has a long history in the literature of data fusion algorithms such as that of Dempster-Shafer theory (DST). Most conflict resolution strategies focus on distributing the conflict among the elements of the frame of discernment (the set of hypotheses that describe the possible decisions for which evidence is obtained) through rescaling of the evidence. These "closed-world" strategies imply that conflict is due to the uncertainty in evidence sources stemming from their reliability. An alternative approach is the "open-world" hypothesis, which allows for the presence of "unknown" elements not included in the original frame of discernment. Here, conflict must be considered as a result of uncertainty in the frame of the discernment, rather than solely the province of evidence sources. Uncertainty in the operating environment of a fused system is likely to appear as an open-world scenario. Understanding the origin of conflict (source versus frame of discernment uncertainty) is a challenging area for research in fused systems. Determining the ratio of these uncertainties provides useful insights into the operation of fused systems and confidence in their decisions for a variety of operating environments. Results and discussion for the computation of these uncertainties are presented for several DST combination rules with simulated and real data sets.

9498-4, Session 1

STAC: A Comprehensive Sensor Fusion Model for Scene Characterization

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In this paper, we present a new multi-sensor fusion model for large-scale complex scene characterization. Due to advances in theory, algorithms, and available computational power, it is now possible to deploy a robot team to extract a large set of rich, semantic information of a scene from raw sensory data in many different modalities. The resulting semantic map can include not just tracking of static and dynamic objects, but also object attributes, terrain information, characterization of structures such as buildings and their layout, and information about activities and events that are occurring in the scene. This set of data can then be used to infer information that can be relevant when deciding how to act, including higher-level information such as routines and patterns that emerge or higher-level intent or objectives of the entities in the scene.

In this paper, we discuss some of the limitations of existing fusion models in covering this level of complexity, and develop a new multi-dimensional model grounded in sensor theory that extends upon existing work. The new model, named STAC, contains spatial, temporal, algorithm, and cognition dimensions. It incorporates many different elements of the problem domain, including spatial representations of the scene at multiple levels of abstraction, temporal dynamics that occur through time, and contextual/semantic information. We provide several contributions through this model, namely: 1) the separation of what type of information is processed (e.g. at what spatial level of abstraction) and the type of processing that is used on it, 2) a temporal dimension supporting analysis of various spatio-temporal aspects of fusion algorithms, 3) explicit separation of directly observed elements versus elements inferred via inference processes, and 4) explicit support for multi-level fusion. We show some example algorithms framed within the new model and highlight its advantages in categorizing, analyzing, and comparing different data fusion techniques.

9498-5, Session 2

Better-than-the-best fusion algorithm with application in human activity recognition

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This paper introduces the Better-than-the-Best Fusion (BB-Fus) algorithm for human activity recognition. The BB-Fus is a simple and effective information fusion algorithm that combines the information from different sources (be it sensors or features) to improve the Correct Classification Rate

(CCR). It can be observed that in most classification problems, different sensors and features might isolate different classes with different CCRs. As a result, this paper searches for the optimal decision tree that best isolates one class at a time in the training phase. Because this search involves the application of the cross-validation algorithm of every possible decision tree configuration (i.e., an iterative and expensive training and testing of different classes to isolate and different sensors/features to use at every level), the training phase can be computationally expensive and time consuming; so, the paper also presents a computationally efficient search algorithm that uses the confusion matrices extracted from each of the sensors/features. The decision tree can then be simply applied in the testing phase and the paper proves that the obtained decision tree improves the CCR over the use of any single sensor or feature. For numerical verification, this paper deploys the BB-Fus algorithm to solve the human activity recognition problem using the REAListic sensor DISPlacement (REALDISP) in which 9 Xsens sensors are used to monitor 33 different human activities. The 9 Xsens sensors are placed on different body parts and each sensor provides acceleration and gyroscope readings. The 33 human activities include various gym exercises such as walking, running and jogging.

9498-6, Session 2

A theoretical performance analysis of discrete data classification when fusing two features

Robert S. Lynch, Analytic Information Fusion Systems, LLC (United States) and Univ. of Connecticut (United States); Peter K. Willett, Univ. of Connecticut (United States)

An approach to discrete classification based on non-informative Dirichlet priors was previously described in [1]. In [2], associated analytical performance results appeared for automatically reducing the dimensionality of the data quantization space, and based on a single feature. In general, the method utilized for discrete classification is referred to as the Bayesian Data Reduction Algorithm (BDRA). BDRA has been developed to be an adaptable classifier that can deal with all types of data (missing, discrete, continuous, unlabeled, and mislabeled), and that works by finding the quantization complexity (referred to as M*) of the training data that corresponds to best posterior classification performance. In other words, BDRA reduces the effect of the “curse of dimensionality,” [3], to find a representation of the data that minimizes the training error, P(e).

In this work, the results shown in [1] and [2] are extended to the case of fusing two features. Specifically, it is of interest to demonstrate theoretically the effect that the overall quantization of the features, M, has on the relative performance of the BDRA when fusing two features. The primary result is to show, with a data model independent of distribution, how the dimensionality reduction aspects of the BDRA improves overall theoretical classification performance on the training data. This result is significant for those interested in the theoretical performance of fusing discrete data (i.e, attributes or classifier decisions), and is an important step towards proving that BDRA always converges to a solution.

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9498-7, Session 2

Flight plan optimization

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Airlines depend on flight planning software for a very accurate flight plan. The fuel required for the flight depends on the route chosen by the dispatcher for that day. Fuel cost accounts for 40 percent of the operating cost. Fuel burn can be optimised by planning on optimised routes.

In this project we aim to develop a new algorithm that is able to produce an optimised route based on the criteria set by the airline. The requirement of the airline can vary from shortest distance, shortest time and minimum fuel. For this project we will be concentrating on shortest distance route from point A to point B. The route search will be based on data extracted from an active navigation data base that is produced on a 28 day AIRAC cycle. The navigation data base is on an ARINC 424 format which is exported to an excel format for the purpose of the project. The most common algorithm that is used for the route search is Dijkstra’s. For this algorithm the result produced is static and the time taken for the search is significantly long.

In this project we have developed a new algorithm for the optimized route search. The basic principle of the algorithm is based on simulated annealing. We have included mutation properties at a portion of the algorithm to obtain better results. We have tested the program to obtain optimized routes for short sectors as well as long sectors. The results obtained are dynamic and fast. This is ideal for random routing feature which is highly sought after by many regional operators.

9498-8, Session 3

Pragmatic open space box utilization: asteroid survey model using distributed objects management based articulation (DOMBA)

Atif F. Mohammad, The Univ. of North Dakota (United States); Jeremy Straub, Univ. of North Dakota (United States)

Big Data management software must deal with enormous amounts of data, prospectively in numerous shapes and sizes. This data can be a traditional database, or in text, audio, visual or other formats. Relational databases cannot support a level where data streaming is happening across multiple areas of structured and non-structured data. NoSQL databases are the answer to this challenge.

Open Space Box is a model for creating data scalability, performance and availability. In this mission, the data which is being transmitted is being collected by a satellite orbiting an asteroid a significant distance from Earth. The Open Space Box framework is used to transmit data to the Earth’s surface or to the International Space Station (as an intermediary).

This approach facilitates the performance of several concurrent research missions which can each use the data transmitted for their particular needs. Given that the data set grows while the satellite is with the orbit of the asteroid (until its orbit deteriorates into the asteroid or some accident, which we cannot predict, occurs, the need for managing data is significant. The Open Space Box framework allows the seamless expansion of data (subject to craft storage limitations), while making sure that transparent Data Recharging occurs on the back-end.

The high-availability architecture means, that in case some of the nodes’ hardware fails, due to any reason, the next working node will start capturing data. Once (or if) the failed node is repaired, it will take charge again (as the MapReduce namenode). The Open Space Box model provides the means to conduct non-traditional data handling at the significant distances applicable to an near-Earth asteroid (NEA) / nea-Earth object (NEO) mission.

For decades, Tables have been used in an RDBMS or Relational Databases,

which are structured, DOMBA (on the other hand) deals with data in terms of collections. No read/write roadblocks to the data exist even though a master/slave architecture is used (as it is the base architecture). Elastic scalability allows for the introduction and removal of nodes or even the addition of an entirely new cluster. This could be critical to expanding a mission that makes an important discovery via the launch of another craft (or collection of small craft). Open Space Box also makes a virtual caching layer available to make sure that continuously accessed data is available in memory and that, upon closing the data file, recharging is applied to the data.

9498-9, Session 3

Gaussian process based modeling and design of experiments for sensor calibration in drifting environments

Feng Yang, Zongyu Geng, Nianqiang Wu, West Virginia Univ. (United States)

It remains a challenge to calibrate a sensor subject to environmental drift. The calibration task is to quantify the relationship between the sensor's response and its exposure condition, which is specified by not only the analyte concentration but also the environmental factors such as temperature and humidity. Achieving a high-quality calibration model is difficult for the following reasons: First, the exposure-condition factors may well affect the response in a nonlinear fashion and also interact nonlinearly with each other. How to obtain the nonlinear calibration model, and how to quantify the uncertainty of the model estimates (e.g., analyte concentrations estimated by the calibration model from observed sensor responses)? These modeling and inference questions are far from being adequately addressed. Second, the fitting of a high-dimensional calibration model generally requires large experimental samples. How to use the least experimental data to obtain a calibration model of the desired quality? This is a design of experiments (DOE) question, and needs to be answered based on the model fitting/inference for sensor calibration. To address these challenges, this work developed a Gaussian Process (GP)-based procedure to efficiently calibrate sensors in drifting environments. Unlike other powerful models (e.g., neural network) previously adopted for sensor calibration, GP renders the potential for valid statistical inference, which allows us to develop a bootstrapping method to quantify estimation uncertainty. Built on such inference ability, the DOE was developed to achieve efficient sampling for sensor calibration. Through simulation studies, the effectiveness and efficiency of the GP-based calibration procedure was demonstrated.

9498-10, Session 3

Uncertainty modeling using copulas for classification

Onur Ozdemir, Boston Fusion Corp. (United States); Sora Choi, Syracuse Univ. (United States); Thomas G. Allen, Boston Fusion Corp. (United States); Pramod K. Varshney, Syracuse Univ. (United States); Karla K. Spriestersbach, Missile Defense Agency (United States)

In this paper we address the problem of characterizing uncertainty for multisensor data fusion in a classification problem. To achieve this goal we propose a joint probability density modeling framework that is based on the statistical theory of copulas. We model the joint density of given multivariate data using copula functions while allowing the ability to incorporate any desired marginal distributions, i.e., any desired modalities. The proposed model is data driven in that the corresponding copula functions and their parameters are learned from the data. Our simulations demonstrate the feasibility of utilizing copula theory for uncertainty characterization in data fusion applications that could lead to (near-) optimal fusion algorithm development for object classification. Our results show that the proposed framework can capture the uncertainties more reliably than current state of the practice and lead to improved classification performance compared to traditional classifiers.

9498-12, Session 4

Effects of using a 3D model on the performance of vision algorithms

Paul Benjamin, Pace Univ. (United States); Damian M. Lyons, Fordham Univ. (United States); Robert Lynch, Analytic Information Fusion Systems, LLC (United States) and Univ. of Connecticut (United States)

In previous work [1,2], we have shown how a 3D model can be built in real time and synchronized with the environment. This world model permits a robot to predict dyamics in its environment and classify behaviors. In this paper we evaluate the effect of such a 3D model on the accuracy and speed of various computer vision algorithms, including tracking, optical flow and stereo disparity. We report results based on the KITTI database and on our own videos [3].

[1] "A Cognitive Approach to Vision for a Mobile Robot", D. Paul Benjamin, Damian Lyons, and Christopher Funk, SPIE Conference on Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications, April 2013.

[2] "Navigation of Uncertain Terrain by Fusion of Information from Real and Synthetic Imagery", Damian Lyons, Paramesh Nirmal and D. Paul Benjamin, SPIE Conference on Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications, April 2012.

[3] http://www.cvlibs.net/datasets/kitti/

9498-13, Session 4

Combining voice and gesture recognition for improved control of UGVs and UAVs

Adrian Stoica, Christopher Assad, Michael Wolf, Jaakko T. Karras, Jet Propulsion Lab. (United States); Marco Arena, Politecnico di Torino (Italy); Randi Williams, Univ. of Maryland, Baltimore (United States)

BioSleeve is a sleeve-embedded sensor array for the forearm, with 16 Electromyography (EMG) electrodes collecting surface EMG, and an IMU; signals are processed to recognize 19 hand gestures with over 97% correct classification rate (CCR). BioSleeve has been used to implement commands for ground platforms (Landroids, Dragon Runner) and aerial platforms (Phantom quadrotor). The CCR decays with time and operational use (movement, fatigue), currently addressed by periodic retraining.

Talk2Bots is a voice-based interface we developed around CMU PocketSphynx, and for which we selected a small vocabulary of 200 words, of which 50 were implemented for commands of Dragon Runner and Phantoms. The CCR while very good in noise-free environments, showing robustness to multiple speakers and different ways of saying the words, is sensitive to noise, and in particular to white noise.

We are currently working towards fusing the two methods, for expanding the range of commands compared to each individual modality, to increase the number of commands recognized above 95% CCR in conditions of extended use, fatigue and noise; our preliminary results indicate the advantage of the fusion.

9498-14, Session 4

Evaluation of parallel reduction strategies for fusion of sensory information from a robot team

Damian M. Lyons, Joseph Leroy, Fordham Univ. (United States)

The advantage of using a team of robots to search or to map an area is that by navigating the robots to different parts of the area, searching or mapping can be completed more quickly. In prior work, we and other researchers have studied the problem of developing effective team dispersion algorithms for such problems. Another crucial aspect of the problem is the combination, or fusion, of data from team members to generate an integrated model of the search/mapping area. In prior work we looked at the issue of removing mutual robots views from an integrated point cloud model build from laser and stereo sensors, leading to a cleaner and more accurate model. Others have also looked at the issue of fusion of robot data from laser and stereo sensors to improve the accuracy of the model. This paper addresses a further challenge: Even with mutual views removed, the stereo data from a team of four robots can require over 600 MB/sec and can quickly swamp a WiFi connection.

This paper proposes and evaluates a communication and fusion approach based on the parallel reduction operation, where data is combined in a series of steps of increasing subsets of the team. Several different strategies for selecting the subsets are evaluated for bandwidth and accuracy constraints. The results are compared with star connectivity as a worst-case and with a balanced binary tree combination as a best case. Parallel reduction assumes associativity of combination, and the paper concludes with a discussion of the implications of this constraint.

9498-15, Session 4

Performance measurements of a mobile manipulator

Roger V. Bostelman, Tsai Hong, Jeremy A. Marvel, National Institute of Standards and Technology (United States)

Future smart manufacturing systems will include more complex coordination of mobile manipulators (i.e., robot arms mounted on mobile bases). Historically, mobile manipulator research has principally focused on control algorithms, including dynamic motions caused by the onboard manipulator motion, especially in undulating terrain, e.g., outdoors. Other areas of mobile manipulator research have been application-oriented, such as trajectory planning for a mobile manipulator with stability considerations and task planning, such as opening doors. However, generalized, precise measurement of mobile manipulators performing routine tasks (e.g., moving to different poses and generating motions profiles) has been relatively non-existent except for simply ensuring that the task is more or less completed. Prior to industrial acceptance for mobile manipulators, just as with their base components of industrial robot arms and automated guided vehicles (AGVs), these new mobile manipulator systems require their manufacturers to have real, verifiable performance data so users can apply these technologies appropriately.

The ISO 9283:1998 industrial robot performance standard describes accuracy and repeatability testing for fixed-base industrial robots for both end-of-motion poses and in-transit trajectories. Currently, there are no industrial robot performance standards for when industrial robots are onboard a moveable base. There is no AGV performance standard, although a new ASTM F45 Committee on Driverless Automatic Industrial Vehicles has been formed, and includes some aspect of mobile manipulation.

Measurement of the robot's Cartesian position and orientation (pose) which is combined with the mobile base's pose is complex where they system can include nine or more degrees of freedom. To simplify measurement, an artifact was designed to allow various geometric patterns to be traced by the robot wielding a tool point sensor to sense the dimensional points along the patterns. Two versions were designed and manufactured to include flat, rotated, convex and concave geometric patterns to trace. The AGV with onboard robot arm will be moved to a series of locations along a straight line, as well as approached from various directions to verify accuracy. It has been shown in previous research that an AGV approaching the same point from various directions is relatively inaccurate as compared to approaching from the same direction.

This paper discusses performance of a mobile manipulator repeatability and accuracy test artifacts, patterns, experiments, and results. Repeatability and accuracy can then be measured using relatively inexpensive, repeatable pattern and point tracking for three main scenarios: A) the AGV stops while the robot accesses all points within its work volume, B) the AGV initially stops while the robot accesses most points within its work volume, informs the AGV to increment to a new point and stop while the robot accesses the remaining points, and C) both the AGV and robot simultaneously while the robot accesses all points. This paper will discuss all scenarios and will detail experiments and results of performing scenarios A and C. There will be a plan or testing scenario B. Although, scenario B tests will be performed, data analyzed and included in the paper if the researchers have the resources prior to the April conference.

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9499-1, Session 1

Hypothesis testing from social data

Md. Tanvir Al Amin, Univ. of Illinois at Urbana-Champaign (United States); Lance M. Kaplan, Jemin George, U.S. Army Research Lab. (United States); Boleslaw Szymanski, Rensselaer Polytechnic Institute (United States); Tarek Abdelzaher, Univ. of Illinois at Urbana-Champaign (United States)

This paper describes a scalable hypothesis tensing service that uses real-time social microblog data feeds to answer the question: are these physical observations anomalous? The service focuses on helping analysts explain large-scale distributed and correlated phenomena that may or may not be anomalous depending on their causes. For example, is this international outbreak of virus-X infections “normal”? Often, experienced analysts have some idea on patterns to look for in observed events that would be supportive of particular hypotheses regarding their underlying cause. Depending on the specific cause, the pattern may be determined as “normal” or “anomalous”. Looking for these event patterns in vast amounts of data, however, can be time consuming. The hypothesis testing service helps the analyst test their hypotheses by quickly checking whether a given hypothesis is borne-out by the underlying data. We demonstrate hypothesis testing using data collected from social media, where the reliability and authenticity of data is itself questionable. Our work jointly (i) ascertains the reliability of individual data times, and (ii) tests multiple hypotheses regarding underlying causes. Accordingly, an analyst can support/reject the assumption of normalcy, and establish the nature of the anomaly, if present.

9499-2, Session 1

Challenges in the use of social media data for the next generation analyst

William R. Grace, Robert Leskovich, The Pennsylvania State Univ. (United States)

Social media increasingly suffuses our lives. Yet with the capabilities for information access and networking social media provides, dangers also arise. Deception represents both an enigmatic and pervasive threat that thrives within the digital landscapes of social media. Deception can take a variety of forms, be propagated through a diverse number of channels, and cause a plethora of damage. This paper provides a review of the state of literature devoted to elements of deception and misinformation in social media, and provides a framework of their recognized characteristics. While previous studies have touched on the role that deception plays in social media, these have generally neglected the analyst’s point-of-view. Identifying themes, characteristics, and behaviors of deception, as well as analytical approaches and existing toolsets posed to identify and counter instances of these threats; this study particularly addresses contemporary challenges and opportunities for the open-source analyst of social media deception.

9499-3, Session 1

Localized emotional barometer: sentiment analysis using Yik Yak data

W. Robert Leskovich, The Pennsylvania State Univ. (United States)

Activity-based Intelligence (ABI) is a rapidly growing methodology within the intelligence community (IC). Over the past few years the definition of ABI has shifted from an intelligence “discipline (Barber, 2012, p. 8; Phillips, 2012)” to a “methodology” (Long, 2013, p. 7; Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, 2011, p. 29) encompassing all of the various INTs. However, the exact definition is not as important as the intent (which has not changed); to provide analysts with a more efficient method to produce intelligence. This represents a shift for the IC from target driven collections to activities driven collection. The traditional warfare concept of identifying a target and then tracking it geospatially does not fit within the irregular warfare paradigm. In this new environment analysts must identify targets by geospatial activities. ABI does this by automating as many of the collection and processing systems as possible. An effective ABI tool will be able to persistently monitor an area of operations (AO) and alert analysts of activity that warrants further investigation.

This methodology has garnered attention from the nation’s highest intelligence authority; General James Clapper. In his remarks at the Defense Strategies Institute Automated ISR Symposium, General Clapper called ABI a “big idea” that would merge Signals Intelligence (SIGINT) with Geospatial Intelligence (GEOINT) (“Remarks of DNI Clapper at Defense Strategies Institute Automated ISR,” 2014). The true application of ABI goes even further, brining ALL INTs together to create full awareness for the analyst.

A crucial component of ABI is the ability to monitor the sentiment of the local population within the area of operations (AO) for a military unit. Sentiment analysis is a subset of Human Terrain/ Geography. This paper describes research on assessing localized sentiment using the new social media site Yik Yak. Yik Yak is similar to Twitter in that it allows users to post character limited posts. However Yik Yak differs from Twitter in two major areas. First, Yik Yak is pseudo-anonymous, allowing and encouraging users to register without a user name, email or phone number (see http://www.yikyakapp.com/). Second, unlike Twitter where less than 1% of Tweets are geo-located (Ulicny & Kokar, 2011, p. 1), every Yik Yak post is geo-located.

Our on-going research seeks to determine if Yik Yak can be used successfully as a sentiment analysis tool. A new toolset is being developed to gather Yik Yak data, perform sentiment analysis and keyword extraction tools, and assess the results. The results will be geospatially represented within the defined area of interest with visualizations dependent on local sentiment. If effective, such data collection and analysis could be a useful tool by acting as a local “emotional barometer” for situation analysts.

9499-4, Session 1

Employing socially driven techniques for framing, contextualization, and collaboration in complex analytical threads

Arthur Wollocko, Michael Farry, Martin Voshell, Michael Jenkins, Charles River Analytics, Inc. (United States); Jennifer Danczyk, Charles River Analytics (United States)

Proliferation of sensor technology has changed Intelligence Analysis (IA). Recent military focus towards sensor platforms has resulted in data overload, placing an increased burden on overtaxed analysts. Technologies have emerged to ease that burden, but focus on individual modalities or sensor platforms rather than analyst needs, not adequately exploiting their unique skills and training.

Specifically, most tools fail to capitalize on the emergence of “digitally native”, “net generation” analysts, who are familiar with socially driven platforms that excel at giving users insight into large data sets while keeping cognitive burdens at a minimum. By using these ubiquitous platforms, net generation analysts have trained skills in discovering new information socially, tracking trends among affinity groups, and disseminating information. However, these functions are currently under-supported by existing tools. In this paper, we describe techniques that employ socially driven techniques to contextualize and frame complex analytical threads throughout the IA process.

This paper focuses specifically on technology development efforts for

one group of "net generation" analysts (those supporting the evolving Processing, Exploitation, and Dissemination (PED) process). It analyzes under-supported functions in their current working environment, focusing on opportunities to improve their ability to discover new information and disseminate insights. We describe our Cognitive Systems Engineering-based approach to developing a novel collaborative enterprise IA system that combines collaboration tools with technologies familiar to "net generation" analysts. This approach's strengths will be detailed in the context of required work support functions, as well as its embodiment within a fully functional technical environment.

9499-5, Session 1

Social network analysis realization and exploitation

Jack Davenport, James J Nolan, Decisive Analytics Corp. (United States)

Tactical Warfighters demand rapid information fusion capabilities to develop and maintain accurate situational awareness and understanding of dynamic enemy threats in asymmetric military operations. The ability to extract meaning in relationships between people, objects, and locations from a variety of text datasets is critical to proactive decision making.

Under this effort we have developed the Social Network Analysis Realization and Exploitation (SNARE) system to extract these relationships. The SNARE approach to social network modeling provides three major advantages to current methods: 1) Automates the construction of detailed multi-mode social networks, 2) Models entities as complex systems of attributes and relationships, and 3) Provides automated support for reasoning about complex social structures.

SNARE provides the following benefits to the tactical Warfighter: 1) The SNARE system automatically builds high-fidelity social networks from text data sets too large to be scrutinized in detail through manual effort. 2) SNARE provides visualizations of the complex social network interactions, providing the Warfighter with enhanced situational awareness. 3) SNARE displays the temporal nature of the relationships in the social networks, thereby giving the analyst a view of how the social networks are changing over time.

9499-6, Session 2

A scalable architecture for extracting, aligning, linking, and visualizing multi-Int data

Craig A. Knoblock, Pedro Szekely, The Univ. of Southern California (United States)

An analyst today has a tremendous amount of data available, but each of the various data sources typically exists in their own silos, so an analyst has limited ability to see an integrated view of the data and has little or no access to contextual information that could help in understanding the data. There is a huge variety of data that is available that can be exploited to understand what is going on in a given area or to answer specific intelligence questions. The available data includes GEOINT data (e.g., satellite imagery, motion imagery, mapping data, etc.), MASINT data (e.g., LIDAR, SAR, hyperspectral data, etc.), SIGINT data (e.g., ELINT, COMINT, etc.), HUMINT data (e.g., intelligence reports, documents, etc.), OSINT (e.g., news articles, photos, videos, telephone books, company web sites, etc), as well as social network and cyber data. The challenge is how to allow an analyst to integrate or fuse the various sources available to answer specific intelligence questions or to detect anomalies.

We have developed the Domain-Insight Graph (DIG) system, which is an innovative architecture for extracting, aligning, linking, and visualizing massive amounts of domain-specific content from unstructured sources. Under the DARPA Memex program we have already successfully applied this architecture to multiple application domains, including the enormous international problem of human trafficking, where we extracted, aligned and linked data from 50 million online Web pages. DIG builds on our Karma data integration toolkit, which makes it easy to rapidly integrate structured data from a variety of sources, including databases, spreadsheets, XML, JSON, and Web services. The ability to integrate Web services allows Karma to pull in live data from the various social media sites, such as Twitter, Instagram, and OpenStreetMaps. DIG then indexes the integrated data and provides an easy to use interface for query, visualization, and analysis.

9499-7, Session 2

Classification of short-lived objects using an interactive adaptable assistance system

Nadia El Bekri, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany); Susanne Angele, Elisabeth Peinsipp-Byma, Fraunhofer IOSB (Germany)

Based on satellite images and certain clearly determined characteristics an aerial image analyst is able to classify different types of objects. An interactive assistance system collects the data from a reference database with a fixed set of reference objects and is therefore mainly designed to evaluate durable single objects. We introduce a concept to a further development of the assistance system in order to be able to handle also short-lived, not clearly classifiable and strong variable objects like dhows. The adaptive assistance system is supposed to assist image analysts by identifying unknown objects and improvised equipment, which are not listed as reference in the master database. For image analysts in missions it is important to detect, analyze, log and if required to find again improvised equipment based on certain characteristics. In order to achieve this goal the system has to fulfill certain conditions.

The image analyst must have the possibility to detect improvised objects in accordance with appropriate procedures while taking into consideration for example the spatial and time reference. Furthermore, we will outline suitable possibilities for the image analyst to categorize improvised objects interactive via geometric shapes as well as a data storage concept for short-lived objects. The adaptive approach describes the option to insert the data (objects) into the system directly and share them with other imagery analysts. So far, the entry and manipulation of data (objects) is granted to a central unit for authorization reasons. Therefore we also designed a data handling concept for on-the-spot uploaded objects.

9499-8, Session 2

Recognition of human-vehicle interactions in group activities via multi-attributed semantic message generation

Vinayak Elangovan, Amir Shirkhodaie, Tennessee State Univ. (United States)

Improved Situational awareness is a vital ongoing research effort for U.S. Homeland Security for the past recent years. Many outdoor anomalous activities involve vehicles as their primary source of transportation to and from the scene where a plot is executed. Vehicles are employed in various activities including: bring in and take out ammunitions, supplies, and people, way to unify, loitering etc. Analysis of the Human-Vehicle Interaction (HVI) dynamics helps to identify interrelated patterns of activities representing potential threats. The objective of this paper is tri-fold. Primarily, we discuss a method for temporal HVI events detection and verification for generation of HVI hypotheses. Secondly, we describe a method for identification of pertinent anomalous behaviors through analysis of state transitions between two successively detected events. Finally, we present a technique for generation of semantic messages effectively describing HVI events and present our experimental results from a simulated scenario in the IRIS Virtual Environment Simulation Model (IRIS-VESM) to demonstrate the effectiveness and efficiency for generation of calibrated datasets through VESM.

9499-9, Session 2

Torpedo: Topic periodicity discovery from text data

Jingjing Wang, Univ. of Illinois at Urbana-Champaign (United States); Hongbo Deng, Yahoo! Inc. (United States); Jiawei Han, Univ. of Illinois at Urbana-Champaign (United States)

Although history may not repeat itself, many human activities are inherently periodic, recurring daily, weekly, monthly, yearly or following some other periods. Such recurring activities may not repeat the same set of keywords, but they do share similar topics. Thus it is interesting to mine topic periodicity from text data instead of just looking at the temporal behavior of a single keyword/phrase. Some previous preliminary studies in this direction pre-specify a periodic temporal template for each topic. In this paper, we remove this restriction and propose a simple yet effective framework to mine periodic/recurrent patterns from text, such as news articles, search query logs, research papers, and web blogs.

We propose a two-step generic framework which takes advantage of both advanced topic modeling technology and the well-studied time series periodicity discovery techniques. First we transform time-stamped text data into topic specific time series by a time dependent topic modeling module with the following intuitions: 1) Top ranked words in a topic should often co-occur in documents. 2) Top ranked words in a topic should often co-occur around the same time. 3) The time distribution of a topic should accommodate the imbalance of the corpus over time. 4) The model should be robust to noise and able to exclude non-discriminative words. Then we analyze the time series to find any inherent periodicity for each topic by a periodicity discovery module. Each module can accommodate various state-of-art techniques to meet the requirements from various applications. We both obtain a clear view of how topics distribute over time and enable the automatic discovery of periods that are inherent in each topic. Theoretical and experimental analyses demonstrate the advantage of our method over existing work. We also present our interesting observations from real word query logs of a commercial search engine.

9499-10, Session 3

A survey of tools and resources for the next generation analyst

David L. Hall, Jacob L. Graham, Emily Catherman, The Pennsylvania State Univ. (United States)

We have previously argued that a combination of trends in information technology (IT) and changing habits of people using IST provide opportunities for the emergence of a new generation of analysts that can perform effective intelligence, surveillance and reconnaissance (ISR) on a “do it yourself” (DIY) or “armchair” approach (see D. L. Hall and J. Llinas, “The emergence of the millennium analyst: how advances in information technology and use enable asymmetric ISR” in Proceedings of the MSS National Symposium on Sensor Data Fusion, Oct. 28, Springfield, VA). Key technology advances include; i) new sensing capabilities including use of micro-scale sensors and ad hoc deployment platforms such as commercial drones, ii) advanced computing capabilities in mobile devices that allow advanced signal and image processing and modeling, iii) intelligent interconnections due to advances in “web N” capabilities, and iv) global interconnectivity and increasing bandwidth. In addition, the changing habits of the digital natives reflect new ways of collecting and reporting information, sharing information and collaborating in dynamic teams. This paper provides a survey and assessment of tools and resources to support this emerging analysis approach. The tools range from large-scale commercial tools such as i2 Analyst Notebook, Palantir, and GeoSuite to emerging open source tools such as GeoViz and DECIDE from university research centers. The tools include geospatial visualization tools, social network analysis tools and decision aids. A summary of tools is provided along with links to web sites for tool access.

9499-11, Session 3

Addressing information management and dissemination challenges for the next-generation analyst

Jesse Kovach, Laurel C. Sadler, Niranjan Suri, Robert P. Winkler, U.S. Army Research Lab. (United States)

Recent technological advances in sensors, computation, and storage have led to the development of relatively inexpensive information, surveillance, and reconnaissance (ISR) assets capable of producing high-resolution data sets. The lower cost combined with the desire to cover larger areas with persistent surveillance capabilities have resulted in wide-scale deployment of these ISR assets and the consequent generation of large volumes of data. Unfortunately, networks have not kept pace with the significant increase in data volume nor has the human ability to process, understand, and make decisions based on the available data.

Given this divergence, the traditional model of collecting data at centralized locations is not always viable. This paper examines two different but complimentary approaches to address the problem of the ever-increasing volume of data. Both approaches rely on the key notion of moving the analysis/query computation of the data to the place of acquisition.

The first relies on analysts specifying their information needs in the form of profiles that are disseminated to the sensors/aggregators, where they reside, matching information as it is acquired and disseminating the data subset to the analyst.

The second approach relies on the notion of mobile agents, small, mobile computations that can be dispatched by the analysts to scour data that has been acquired and archived at the edge. These agents embody specific queries for information and can move between sensor assets performing correlation/fusion tasks prior to selecting a data subset and relaying that to the analyst.

9499-12, Session 3

Next generation data harmonization

Justin M. Del Vecchio, Jillian Chaves, Adam Czerniejewski, Greg Tauer, Ryan M. Brown, CUBRC (United States); Tim Perkins, Chandler Armstrong, U.S. Army Corps of Engineers (United States); Ronald Rudnicki, CUBRC (United States)

Intelligence analysts are presented with an ever increasing number of data sources for analysis to solve problems. Often, analysts are able to identify subsets of data sources suitable for answering pertinent questions. However, harmonizing these data sources is a challenge and analysts quickly find themselves mired in time consuming manual processes to align and extract meaningful information. A solution is to embrace semantic technologies and leverage the many recent breakthroughs they afford in the harmonization and representation of heterogeneous data. An example prototype using these semantic technologies is in development where input to the system is a set of data sources documenting violent events that need to be aligned and analyzed. The prototype applies a novel approach where data sources are aligned to a common ontology and then events across data sources correlated using the fine-grained ontology mappings in a cloud environment. Of particular interest is the application of a holistic ontology, tools to speed the alignment process (of both structured and unstructured data), and implementation of a geospatial-centric user interface to analyze resolved results. The prototype serves a sound foundation to layer additional data sources that complement the original set of data sources.

9499-13, Session 3

Intelligence reach for expertise (IREx)

Christina Hadley, QED Systems, LLC (United States); James R. Schoening, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States); Yonatan Schreiber, CUBRC (United States)

IREx is a search engine for Intelligence Analysts to find collaborators. U.S. Army Field Manual 2 (Intelligence) calls for collaboration within and outside the area of operations, but finding the best collaborator for a given task can be challenging. IREx will be demonstrated as part of Actionable Intelligence Technology Enabled Capability Demonstration (AI-TECD) at the E15 field exercises at Ft. Dix in July 2015. It includes a Task Model for describing a task and its needed competencies, and uses an ontology foundation for semantic matching and for maintaining consistency as the model is extended for unique domains.

FM-2 defines 'Intelligence Reach' as the ".process by which intelligence organizations proactively and rapidly access information from, receive support from, and conduct direct collaboration and information sharing with other units and agencies, both within and outside the area of operations." Collaboration tools are being developed, but they assume collaborators are already matched up. If not, IREx can be used to find collaborators with the needed expertise and who also available. Another use could be for a learner who completes self-paced training but needs to practice these skills on a real task. They could post a standing offer to help on any task that would enable them to use their new skills. Or, they could set up a standing query that would alert them to postings seeking this skill.

The IREx Task Model is advancing toward becoming an IEEE standard. It is currently an approved IEEE Study Group, after which follows a standards working group, then a balloting group, and finally an IEEE standard. Members of the Study Group, including those from the U.S. Army, created a free web service to refine the Task Model and how it functions in a working search application. Those interested are invited to join the IREx project or the parallel IEEE activities.

9499-14, Session 3

Utilizing context for improved threat analysis

Eric G. Little, Geoff Gross, Modus Operandi, Inc. (United States)

Analyzing threat conditions is difficult due to the large amounts of noisy data to which analysts are normally exposed to. Discerning between entities, events, activities, or states of affairs that are threatening, compared to those which are not, normally requires an understanding of context. Context is formally defined here as a mereotopological state of affairs that serves as the background environment for threat conditions. Context can relate to a spatial location, a temporal period, how many individuals are engaging in an activity (and their spatio-temporal approximation to one another), etc. Entities exist within and move through their environments, which serve as their contexts. For example, a person throwing an object may not be threatening, unless this activity occurs in a certain location (e.g., in the stands at a sporting event, outside of an embassy's gate, or near the White House). A large number of money transfers may not be threatening, unless occurring rapidly in a very short period of time commensurate with fraudulent activity. This paper describes a means for utilizing this approach to develop high-level fusion algorithms that can appropriately capture not only L1 and L2 items, but better understand and compute over the L3 items associated with threat. This, in turn, can be used to trigger appropriate alerting mechanisms providing both analysts and automated agents with near-real-time capabilities for understanding and reacting to threatening conditions. Users can access and utilize this capability within a host of software applications that provide improved human-in-the-loop analysis.

9499-15, Session 4

Collaborative interactive visualization: exploratory concept

Marielle Mokhtari, Valérie Lavigne, Frédéric Drolet, Defence R&D - Valcartier (Canada)

Dealing with an ever increasing range of data of diverse types is a challenge that (Intelligence) analysts face day to day. Digital data is regularly accessed by these people in order to share it, to visualize it, to comprehend it, to analyze it either individually or as a team, to fuse it with another data, or to form decisions. Increasing individual and collective comprehension goes through collaboration between (co-localised and/or geographically dispersed) people. Better is the collaboration, better will be the comprehension. However, choosing the appropriate collaboration approach will likely involve many trade-offs between the various facets of the problem under study.

Technology now allows people to connect and collaborate in settings as varied as across mobile devices, over networked computers, display walls, tabletop surfaces, to name just a few. A powerful collaboration includes the visualization aspect which is a means to achieve effective human communication. Multi-dimensional visualization in an immersive display system (e.g. 3D display wall, CAVE, HMD...) is also of consideration in our digitized world because these systems support, among other things, (1) the ability to simultaneously display a huge amount of data and represent multidimensional dataset more efficiently compared to any other display devices, (2) to help escaping the conventional bias towards 2D computing by organizing content more effectively in 3D, (3) to analyze and interpret data faster, and (4) to explore data in a more intuitive way through interactions with visually rendered data. Interactive visualization strengthens collaboration for the reason that this approach is conducive to incrementally building a mental assessment of the data meaning. But the way to share, access and manipulate a representation remains an ongoing challenge, especially when this representation is complex in terms of content or scale and when the systems having to exploit it are as varied as those mentioned before.

The purpose of this article is (1) to discuss challenges and opportunities related to interactive and collaborative visualisation; (2) to present a collaborative interactive visualization concept allowing to share, access and manipulate a virtual content between people that are co-localised or geographically dispersed and potentially exploiting different operating systems by conciliating technological and representation constraints; and (3) the way this concept will be integrated in the Sensemaking Support System developed for the Joint Intelligence Collection and Analysis Capability project at DRDC Valcartier.

9499-16, Session 4

Visualization approaches for displaying measures of sentiment

Sue E. Kase, Heather E. Roy, Daniel N. Cassenti, U.S. Army Research Lab. (United States)

The overall purpose of intelligence analysis platforms is to extract key information from multi-source data. Ultimately, these systems are meant to save intelligence analysts time and effort by offering knowledge discovery capabilities. However, intelligence analysis platforms should be designed with human factors in mind. Poorly designed intelligence analysis platforms can hinder the knowledge discovery process, or worse, promote the misinterpretation of analysis results. Future intelligence systems must be critical enablers for improving speed, efficiency, and effectiveness of command-level decision making. Human-centered research is needed to address the challenge of visualizing large data collections to facilitate orientation and context, enable the discovery and selection of relevant information, and provide dynamic feedback for identifying changes in the state of a targeted region or topic. From the perspective of the Human as a Data Explorer, this study investigates the visual presentation of intelligence information to support timely and accurate decision making.

This investigation is a starting point in understanding the rich and varied set of information visualizations sponsored by the Army in recent years. A human-subjects experiment explores two visualization approaches against a control condition for displaying sentiment about a set of topics with an emphasis on performance metrics including response time, accuracy, and number of mouse clicks needed to answer persons of interest comparisons. The resulting data analysis is the first in a series of experiments that will provide input for technology development that can inform future interface designs and system prototypes.

9499-17, Session 4

Conversational sensemaking

Alun D. Preece, William Webberley, Cardiff Univ. (United Kingdom); Dave Braines, IBM United Kingdom Ltd. (United Kingdom)

Recent advances in natural language question-answering systems and context-aware mobile apps create opportunities for improved sensemaking in a tactical setting. Users equipped with mobile devices act as both sensors (able to acquire information) and effectors (able to act in situ), operating alone or in collectives. The currently-dominant technical approaches follow either a pull model (e.g. Apple's Siri or IBM's Watson which respond to users' natural language queries) or a push model (e.g. Google's Now which sends notifications to a user based on their context). There is growing recognition that users need more flexible styles of conversational interaction, where they are able to freely ask or tell, be asked or told, seek explanations and clarifications. Ideally such conversations should involve a mix of human and machine agents, able to collaborate in collective sensemaking activities with as few barriers as possible. Desirable capabilities include adding new knowledge, collaboratively building models, invoking specific services, and drawing inferences. As a step towards this goal, we collect evidence from a number of recent pilot studies including natural experiments (e.g. situation awareness in the context of organised protests) and synthetic experiments (e.g. human and machine agents collaborating in information seeking and spot reporting). We identify some principles and areas of future research for "conversational sensemaking".

9499-18, Session 4

Collaborative human-machine analysis using a controlled natural language

David Mott, IBM United Kingdom Ltd. (United Kingdom); Donald R. Shemanski, The Pennsylvania State Univ. (United States); Cheryl Giammanco, US Army Research Laboratory, Human Research & Engineering Directorate (United States); Dave Braines, IBM United Kingdom Ltd. (United Kingdom)

A key aspect of an analyst's task in providing relevant information from data is the reasoning about the implications of that data, in order to build a plausible picture of the real world situation. This requires human cognition involving problem solving, deduction, assumption making and the review of rationale, based upon domain knowledge about the characteristics, interrelationships and behaviours of the individuals, events and environment that may be involved. For a computer system to assist an analyst in such a task, it must be capable of following a similar reasoning process, using similar concepts to that of the analyst, so that a natural collaboration may occur between analyst and machine.

For this purpose we use a Controlled Natural Language, a subset of English called ITA Controlled English (CE), to represent analyst's domain knowledge and reasoning, in a form that it is readable and understandable by the analyst without computer knowledge, whilst at the same time understandable by the machine. CE can be used to express the rules and constraints of the domain, the data that is given to the analyst as well as the conclusions that are inferred and the assumptions made, thus facilitating the interaction between man and machine. A CE reasoning and modeling system can perform inference based upon the data and provide the user with conclusions together with their rationale. We have explored the use of "active" Microsoft Word documents as the main interface to such a CE system, allowing the user to embed their conceptual model within a conventional document whilst providing integrated facilities for running the reasoning, querying the results and providing explanation.

To experiment with CE for assisting analysts, we have studied a specific logical problem, the "Analysis Game", given as part of a training course for intelligence analysts, which shares key characteristics and presents the type of deductive challenges inherent in many real-world analytic scenarios. The problem has been successfully formulated in CE, leading to a solution, but we discovered that an iterative approach to the formulation was needed, mirroring a more human-like approach where a person might develop an understanding of the problem and its essential characteristics and reasoning steps by the incremental construction of relevant concepts and rules to represent the problem. By a sequence of interactions between the user and the CE system, the user may modify the conceptual model, see the effects of the model in terms of the conclusions, or lack of conclusions, when run against the data and devise new concepts to better solve the problem. We discuss how such interactions might occur, and propose that such techniques could lead to better collaborative tools to assist the analyst.

9499-19, Session 4

Enhancing decision-making by leveraging human intervention in large-scale sensor networks

Enrico Casini, Florida Institute for Human & Machine Cognition (United States); Jessica Depree, Modus Operandi, Inc. (United States); Niranjan Suri, Florida Institute for Human & Machine Cognition (United States) and U.S. Army Research Lab. (United States); Jeffrey M. Bradshaw, Florida Institute for Human & Machine Cognition (United States); Teresa Nieten, Modus Operandi, Inc. (United States)

Extensive deployment of sensor networks in recent years has led to the generation of large volumes of data. One approach to processing such large volumes of data is to rely on parallelized approaches based on architectures such as MapReduce. However, fully-automated processing without human intervention is error prone. Supporting human involvement in processing pipelines of data in a variety of contexts such as warfare, cyber security, threat monitoring, and malware analysis leads to improved decision-making. Although this kind of human-machine collaboration seems straightforward, involving a human operator into an automated processing pipeline presents some challenges. For example, due to the asynchronous nature of the human intervention, care must be taken to ensure that once a user-made correction or assertion is introduced, all necessary adjustment and reprocessing is performed. In addition, to make the best use of limited resources and processing capabilities, reprocessing of data in light of such corrections must be minimized. This paper introduces an innovative approach for human-machine integration in decision-making for large-scale sensor networks that rely on the popular Hadoop MapReduce framework.

9499-20, Session 5

One decade of the DFIG model

Erik Blasch, Air Force Research Lab. (United States)

The last major revision of the Joint Directors of the Laboratories Information Fusion model in 2004 incorporated the analyst and was coined the Data Fusion Information Group (DFIG) model. Since that time, developments in information technology (e.g., cloud computing, applications, and multimedia) have altered the role of the analyst. Data production has outpaced the analyst; however the analyst still has the role

of data refinement and reporting. In this paper, we highlight three issues being addressed by the DFIG model. One example is the vast amount of data available that has to be accessed. It is the role of the analyst to provide information queries so that indexed data can be retrieved. The second example is data production which requires the analyst to digest the data into a condensed and meaningful form. The last example is the interpretation of the resolved information from data that must include cultural, social, and contextual information not inherent in the data itself. Through a use-case example, the DFIG developments in the last decade demonstrate the usability of the JDL process model as augmented by the DFIG model to bring together the user (analyst of operator) and the role of the machine (information fusion of information manager).

9499-21, Session 5

Combining human and machine processes (CHAMP)

Moises Sudit, Univ. at Buffalo (United States); Michael Hirsch, Stetson Univ. (United States); David Sudit, BAE Systems (United States)

Machine Reasoning and Intelligence is usually done in a vacuum or without consultation of the ultimate decision-maker. The late consideration of the human cognitive process creates some major problems in the use of automated systems to provide reliable and actionable information that users can trust and depend on to make the best Course-of-Action (COA). On the other hand, if automated systems are created exclusively based on human cognition, then there is a danger of developing systems that don't push the barrier of technology and are mainly done for the comfort level of the selected Subject-Matter-Expert (SME). Our presentation of Combining Human And Machine Processes (CHAMP) is based on the notion of formulating a Mathematical Model to provide an optimal strategy on where, when, how and which Human Intelligence should be injected within a Machine Reasoning and Intelligence process. This insertion should be based on the criteria of improving the quality of the output of the automated process while maintaining the required computational efficiency for a COA to be actuated in timely fashion. So our work will address the following research areas:

• Consistency with a mission: Injection of Human Reasoning and Intelligence within the reliability and temporal needs of a mission to attain Situational Awareness, Impact Assessment and a Course-of-Action.

• Support the use of data that is uncertain, incomplete, imprecise and contradictory (UIIC): Develop a mathematical model to suggest the insertion of a cognitive process within a machine reasoning and intelligent system so as to minimize UIIC concerns.

• Develop systems that include humans in the loop whose performance can be analyzed and understood to provide feedback to the sensors.

9499-22, Session 5

Composable systems

James Llinas, Univ. at Buffalo (United States); Kevin Barry, Lockheed Martin Corp. (United States)

The Lockheed Martin Advanced Technology Laboratory's (LM ATL) are collaborating with Professor James Llinas to develop a mixed-initiative associate system for intelligence analysts to facilitate reduced analysis and decision times while proactively foraging and presenting relevant information based on the analyst's needs, current tasks and cognitive state. New ISR enterprise management and analytic features will allow any analyst (e.g., SIGINT, Full-Motion Video, All Source) to drive the collection, fusion, and analysis processes in order to have enough context and situation awareness to rapidly analyze large data sets and support multiple missions with derived work products.

Today's exploitation and analysis systems have largely been designed to be sensor or data driven, often missing the mark on delivering to the analyst information that directly supports his or her evolving tasking and work product development preferences. Our interactions with analysts have illuminated the analyst's need to impact the information collection and analysis capabilities in a variety of ways, including understanding data options, collection synchronization, analysis composition, hypothesis validation, mission-oriented query, and work product development. Each of these needs exists today, and we anticipate that they will evolve significantly as US forces engage threats in denied environments. We strive to create a Goal-Oriented Associate System that teams with the Analyst to increase the flexibility and capability to effectively utilize Multi-INT fusion and analytics tailored to the analyst's mission needs; Critical components of this associate system apply emerging methods in information integration, information foraging, hard/soft fusion, pattern analysis, structured argumentation based COA hypothesis synthesis.

9499-23, Session 5

Generalist analysts' at the edge and distributed analytics

Gavin Pearson, Bob Madahar, Defence Science and Technology Lab. (United Kingdom)

Joint Vision 2020 highlights that achievement of 'full spectrum dominance rests upon information superiority' and that information capabilities are changing rapidly. Similarly the Eight Great Technologies and McKinsey Global Institute have highlighted the criticality of 'Big Data' technologies.

But most 'Big Data' technologies are predicated on the availability of high quality/bandwidth distributed information Infrastructure and service rich systems, and much of the technology is designed for use by highly trained data scientists. In deployed military operations the context is radically different; many analysts are generalists as opposed to highly trained data scientists, and the information infrastructure is frequently significantly thinner, sparse and brittle. Further operations are highly dynamic, temporally challenging, and in an unfamiliar socio-cultural environment. As Joint Vision 2020 states 'the need to shape ambiguous situations at the low end of the range of operations will present special challenges.

This paper outlines the S&T challenges associated with adapting 'Big Data' technologies to build a distributed analytic capability for the deployed operations. In particular we will discuss issues associated with:

a) The data analytic platforms and the need for adaption to a distributed coalition environment and tactical information infrastructures;

b) The Volume, Velocity, Variety, Veracity, Viscosity and Value of information and information processing, storage and distribution capabilities;

c) The nature of the situations to be understood and the resulting impact on abstract representations and synergistic human-machine teams;

d) The role of the human in collaboratively extracting understanding from information and directing the information system.

9499-24, Session 5

Argumentation and fusion of soft-hard information for threat prediction

Galina L. Rogova, Univ. at Buffalo (United States); Ronald R. Yager, Iona College (United States)

The modern day threat environment is characterized by a huge amount of information of variable quality often uncertain, unreliable, and irrelevant. Human analyst faces a difficult problem of combining and making sense of these pieces of evidence while facing possibly unknown circumstances, limited or inexistent a priori information, decision making time pressure, and possible catastrophic consequences of unrecognized threats. This paper presents a human-machine model designed in the framework of argumentation, uncertainty theories, and anytime decision making. This model combined two components. The first component is a human-based evidential reasoning for construction of pro and contra arguments for each of the three threat parts (intent, opportunity, and capability) while considering transient information as pieces of alternative stories (hypotheses) based on "what might happen." The second one represents abductive reasoning, in which beliefs in each of these arguments are combined to produce beliefs in each threat component. These beliefs are further fused to obtain probabilities of the competing stories under consideration. These probabilities are used for selecting decisions on either alerting an analyst on potential or imminent threat, or continuing observations for making better decision. One of the problems here relates to the fact that arguments are based on heterogeneous information: sensor readings, information source subjective opinions, the outputs of various processing such as sensor fusion and video analysis. Thus uncertainty characterizing different arguments is expressed in the framework of different uncertainty theories (probability, possibility, belief). The paper addresses the problem of combining arguments while considering and unifying various uncertainty representations.

9499-25, Session PTue

Dealing with extreme data diversity: extraction and fusion from the growing types of document formats

Peter David, Nichole Hansen, James J. Nolan, Pedro Alcocer, Decisive Analytics Corp. (United States)

Despite years of effort and hype, Semantic Web research has not produced general-purpose technology that can solve the DoD's massive data integration problems. Under the Semantic Web paradigm, the meaning of data is explicitly defined by premade taxonomies and ontologies that are unified through logic and rules and whose use is prescribed for all data exchanged in a system or network. Unfortunately, it has become clear that a world in which all data is aligned with a consistent and universally available schema is not close at-hand. One of the areas where the absence of a universal method for metadata management is most painful is in the area of open-domain document analysis.

The growth in text data available online is accompanied by a growth in the number of document formats. Corpora with extreme heterogeneity are common. In the presence of extreme document diversity even simple tasks such as extracting document titles, authorship information, or top level headings can be a difficult and time-consuming process. One important reason for this difficulty is the proliferation of metadata-less formats such as PDF files of scanned documents, and text data formatted solely through typographic conventions that were improvised or defined informally by the author, without an underlying, machine-readable explanation of how document structure and metadata is represented through text formatting.

Our ongoing research adopts the view that the problem of understanding and exploiting document organization and structure is not a problem of matching structure and content to predefined ontologies or taxonomies. Ultimately, the problem of document understanding is a problem of understanding the communicative intent of its author. Rather than apply a top-down, schema-based approach to document modeling that uses a priori schemas as a starting point for document understanding, we use a bottom-up, data driven approach that learns how people view and organize their content. Because we view authorship as a communication phenomenon whose patterns and rules must be discovered, we have designed a research program that is inspired by and based on the tools of computational linguistics and machine learning.

9499-26, Session PTue

Towards an automated intelligence product generation capability

Timothy W Hawes, Alison M. Smith, James J Nolan, Decisive Analytics Corp. (United States)

Creating intelligence information products is a time consuming and difficult process for analysts faced with identifying key pieces of information relevant to a complex set of information requirements. Complicating matters, these key pieces of information exist in multiple modalities scattered across data stores, buried in huge volumes of data. This results in the current predicament analysts find themselves; information retrieval and management consumes huge amounts of time that could be better spent performing analysis. The persistent growth in data accumulation rates will only increase the amount of time spent on these tasks without a significant advance in automated solutions for information product generation.

We present a product generation tool, Automated PrOduct Generation and Enrichment (APOGEE), which aims to shift the bulk of the effort in information product creation from data discovery and management to analysis by automating the information product creation process. APOGEE discovers text, imagery, video, and audio relevant to information requirements for inclusion in information products using semantic and statistical models of unstructured content. APOGEE's mixed-initiative interface, supported by highly responsive backend mechanisms, allows analysts to dynamically control the product generation process ensuring a maximally relevant result. The combination of these capabilities results in significant reductions in the time it takes analysts to produce information products while helping to increase the overall coverage of products. The end result of the APOGEE effort is a flexible end-to-end system that can be rapidly deployed in new operational settings.

9499-27, Session PTue

Entity resolution using cloud computing

Alex James, Greg Tauer, Adam Czerniejewski, Ryan M. Brown, Jesse Hartloff, Jillian Chaves, Moises Sudit, CUBRC (United States)

Roles and capabilities of analysts are changing as the amount of data grows. Open-source content is abundant and users are becoming increasingly dependent on automated capabilities to sift and correlate information. Entity resolution is one such capability. It is an algorithm that links entities using an arbitrary number of criteria (ie: identifiers, attributes, etc.) from multiple sources. This presentation demonstrates a prototype capability, which identifies enriched attributes of individuals stored across multiple sources. Here, the system first completes its processing on a cloud-computing cluster. Then, in a data explorer role, the analyst evaluates whether automated results are correct and whether attribute enrichment improves knowledge discovery.

SPIE. DSS SENSING TECHNOLOGY + APPLICATIONS

Conference 9500: Quantum Information and Computation XIII

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9500-1, Session 1

Towards secure networks using entangled photons and spins *(Invited Paper)*

Dirk R. Englund, Edward H. Chen, Tim Schroeder, Luozhou Li, Catherine Lee, Jacob C. Mower, Massachusetts Institute of Technology (United States)

Quantum key distribution (QKD) enables participants to exchange secret information over long distances with unconditional security. Here, we discuss a high-dimensional QKD protocol to maximize the secure key capacity over an optical channel, given experimental constraints. Our security proof rests on temporal and spectral correlations of entangled photon pairs. This resource-efficient QKD system is implemented at telecom wavelength, is suitable for optical fiber and free-space links, and is compatible with wavelength-division multiplexing. We also discuss recent efforts of integrating QKD hardware on photonic integrated circuits. The full protocol is discuss in J. Mower et al, Phys. Rev. A 87, 062322 (2013). However, the reach of QKD systems is still fundamentally limited by photon loss. In the second part of the talk, we discuss recent advances in solid state quantum memory for quantum repeaters. In particular, we will discuss quantum memories consisting of nitrogen vacancy (NV) center spatially implanted in high-quality photonic crystal nanocavities in single-crystal diamond. For more information, please see arXiv:1409.1602.

9500-2, Session 1

Performance limits for single-photons, correlated-photons, and entangled-photons for quantum key distribution over fiber optics network topologies

Eric Donkor, Fahad A. Althowibi, Ryan Williams, Univ. of Connecticut (United States)

We present and compare the characteristic performance of single-photons, correlated-photons, and entangled-photons for quantum key distribution over various fiber optic network topologies. The networks include the RING, BUS, and STAR. Quantum bit-error rate is determined for each network as function of number of users, and transmission distance. The trade off between number of users and transmission distance is presented. The robustness of the QKD against eavesdropping is evaluated for each architecture.

9500-3, Session 1

A quadnat continuous-variable quantum key distribution using collated photons

Eric Donkor, Univ. of Connecticut (United States); Reinhard Erdmann, Advanced Automation Corp. (United States); David H. Hughes, Air Force Research Lab. (United States); Patrick D. Kumavor, Univ. of Connecticut (United States)

We propose a quantum key distribution system based on the generation and transmission of random continuous variables in time, energy (wavelength), phase, and photon number. The bounds for quantum measurement in our scheme is determined by the Heisenberg uncertainty principle, rather than quadrature measurements of entangled states or the no-cloning of single quantum particles. Correlated measurements are performed in the energy-time, and momentum-displacement frames. As a result the QKD protocols for generation of raw-keys, sifted-keys, privacy amplifications etc are more robust to offer higher level of security against individual or muti attacks. The paper presents network architecture designed for plug-and-play, the QKD protocol, determination of the quantum bit error rate, and estimation of system performance against eavesdropping.

9500-4, Session 1

Quantum teleportation for keyless cryptography

Abhishek Parakh, Univ. of Nebraska at Omaha (United States)

This paper presents a protocol that uses quantum teleportation for securely sending a message from sender to receiver. The protocol assumes that the communicating parties share pairs of entangled qubits before the protocol begins. However, unlike previous protocols we do not use these qubits to generate an encryption key but to teleport the message qubit to the receiver in such a way that any eavesdropper listening to the communication cannot deduce any information about the message qubit.

The proposed protocol not only presents a new direction in quantum cryptography where not explicit key exchange is required but provides the following two advantages as well:

1. Unlike quantum key distribution protocol no qubits are “wasted” or discarded due to measurement in the wrong bases. As a consequence the proposed protocol provides bit rates higher than any other quantum cryptographic protocol.

2. Any arbitrary state of the qubit can be transmitted rather than just states in one of the two orthogonal bases.

9500-5, Session 1

Implementing Diffie-Hellman key exchange using quantum EPR pairs

Sayonnha Mandal, Abhishek Parakh, Univ. of Nebraska at Omaha (United States)

This paper implements the concepts of perfect forward secrecy and the Diffie-Hellman key exchange in demonstrating the principle of the key exchange, using quantum EPR pairs to establish and share a secret key between two non-authenticated parties Alice and Bob to transfer messages between each other without the risk of compromise. Current implementations of quantum cryptography are based on the BB84 protocol, which is susceptible to siphoning attacks on the multiple photons emitted by practical laser sources. This makes BB’84-based quantum cryptography protocol unsuitable for network computing environments. Diffie-Hellman does not require the two parties to be mutually authenticated to each other, yet it can provide a basis for a number of authenticated protocols, most notably the concept of perfect forward secrecy. The work proposed in this paper provides a new direction in utilizing quantum EPR pairs in quantum key exchange. Although, classical cryptography boasts of efficient and robust protocols like the Diffie Hellman key exchange, in the current times, with the advent of quantum computing they are very much vulnerable to eavesdropping and cryptanalytic attacks. Using quantum cryptographic principles, however, these classical encryption algorithms show more promise and a more robust and secure structure for applications. The unique properties of quantum EPR pairs also, on the other hand, go a long way in removing attacks like eavesdropping by their inherent nature of one particle of the pair losing its state in the occurrence of measurement of the other.

The concept of perfect forward security is also revisited in this paper to attribute tighter security to the proposed protocol.

9500-6, Session 1

Provably Secure Time Distribution For the Electric Grid

Amos M. Smith, Phil G. Evans, Oak Ridge National Lab. (United States); Brian P Williams, Oak Ridge National Laboratory (United States); Warren P. Grice, Oak Ridge National Lab. (United States)

We demonstrate a quantum time distribution (QTD) method that combines the precision of optical timing techniques with the integrity of quantum key distribution (QKD). Critical infrastructure is dependent on microprocessor and programmable logic-based monitoring and control systems. The distribution of timing information across the electric grid is accomplished by GPS signals which are known to be vulnerable to spoofing. We demonstrate a method for synchronizing remote clocks based on the arrival time of photons in a modified QKD system. This has the advantage that the signal can be verified by examining the quantum states of the photons similar to QKD.

9500-7, Session 1

Secret Key Generation via a Modified Quantum Secret Sharing Protocol

Amos M. Smith, Phil G. Evans, Benjamin J. Lawrie, Oak Ridge National Lab. (United States); Matthieu Legré, id Quantique SA (Switzerland); Pavel Lougovski, William Ray, Oak Ridge National Lab. (United States); Brian P Williams, Oak Ridge National Laboratory (United States); Bing Qi, Warren P. Grice, Oak Ridge National Lab. (United States)

We describe a novel method for distributing random secret information between two and only two parties based on N-party single-qubit Quantum Secret Sharing (QSS). We demonstrate our protocol with N = 3 parties on a quantum channel. Our system is based on the Clavis2 QKD system developed by ID Quantique. Any two of the N participants can build a secret key with collaboration from the remaining N-2 parties and partial information from each other. This allows for the creation of two-party secret keys were standard QSS does not and reduces the number of resources needed to implement single photon QKD on the grid.

9500-8, Session 1

Analysis of the secrecy of the running key in quantum encryption channels using coherent states of light

Vladimir V. Nikulin, Binghamton Univ. (United States); David H Hughes, John Malowicki, AFRL (United States); Vijit Bedi, Intel Corporation (United States)

Free-space optical communication channels offer secure links with low probability of interception and detection. Despite their point-to-point topology, additional security features may be required in privacy-critical applications. Encryption can be achieved at the physical layer by using quantized values of photons, which makes exploitation of such quantum communication links extremely difficult. One example of such technology is keyed communication in quantum noise, a novel quantum modulation protocol that offers ultra-secure communication with competitive performance characteristics. Its utilization relies on specific coherent measurements to decrypt the signal. The process of measurements is complicated by the inherent and irreducible quantum noise of coherent states. This problem is different from traditional laser communication with coherent detection; therefore continuous efforts are being made to improve the measurement techniques. Quantum-based encryption systems that use the phase of the signal as the information carrier impose aggressive requirements on the accuracy of the measurements when an unauthorized party attempts intercepting the data stream. Therefore, analysis of the secrecy of the data becomes extremely important. In this paper, we present the results of a study that had a goal of assessment of potential vulnerability of the running key. Basic results of the laboratory measurements are combined with simulation studies and statistical analysis that can be used for both conceptual improvement of the encryption approach and for quantitative comparison of secrecy of different quantum communication protocols.

9500-9, Session 1

Multidimensional manifold extraction for multicarrier 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)

We introduce the multidimensional manifold extraction for multicarrier continuous-variable (CV) quantum key distribution (QKD). The manifold extraction utilizes the resources that are injected into the transmission by the additional degrees of freedom of the multicarrier modulation. We demonstrate the results through the AMQD (adaptive multicarrier quadrature division) scheme, which granulates the information into Gaussian subcarrier CVs and divides the physical link into several Gaussian sub-channels for the transmission. We prove that the exploitable extra degree of freedom in a multicarrier CVQKD scenario significantly extends the possibilities of single-carrier CVQKD. The manifold extraction allows for the parties to reach decreased error probabilities by utilizing those extra resources of a multicarrier transmission that are not available in a single-carrier CVQKD setting. We define the multidimensional manifold space of multicarrier CVQKD and the optimal tradeoff between the available degrees of freedom of the multicarrier transmission. We also extend the manifold extraction for the multiple-access AMQD-MQA (multiuser quadrature allocation) multicarrier protocol. The additional resources of multicarrier CVQKD allow the achievement of significant performance improvements that are particularly crucial in an experimental scenario.

9500-10, Session 2

Compressive quantum sensing

John C. Howell, Univ. of Rochester (United States); Gregory A. Howland, Air Force Research Lab. (United States); Samuel Knarr, Daniel Lum, James Schneeloch, Univ. of Rochester (United States)

Compressive sensing utilizes sparsity to realize efficient image reconstruction. It is a valuable processing technique when cost, power, technology or computational overhead are limited or high. In the quantum domain technology usually limits efficient acquisition of weak or fragile signals. I will discuss the basics of information theory, compression, and compressive sensing. I will then discuss our recent work in compressive sensing. The topics of discussion include low-flux laser Radar, photonic phase transitions, high resolution biphoton ghost imaging, Ghost object tracking, 3D object tracking and high dimensional entanglement characterization. I will touch lightly on our current work of rapid wavefunction reconstruction and wavefront sensing. As an example, we were able efficiently and rapidly reconstruct high dimensional joint probability functions of biphotons in momentum and position. With

conventional raster scanning this process would take approximately a year, but using double-pixel compressive sensing, the pictures were acquired in a few hours with modest flux.

9500-11, Session 2

Multi-path time-delay detection and estimation using a quantum annealer

John J. Tran, Information Sciences Institute (United States); Kevin J. Scully, Darren L. Semmen, Walter E. Lillo, The Aerospace Corp. (United States); Robert F. Lucas, Information Sciences Institute (United States)

The detection and resolution of closely spaced objects (CSO) on a two-dimension focal plane are important parts of automated target recognition and tracking. The detection and mitigation of multi-path time-delay (MPTD) signals are important parts of GPS and satellite communications. These two signal processing problems, on the surface, appear to be unrelated; however, when examined more closely, the MPTD problem can be viewed as a one-dimensional CSO problem. Of the two problems, the CSO resolution algorithm is more widely studied and has been shown to be combinatorial. To avoid being trapped by local minima of the cost function, a brute force algorithm, requiring time and/or space that scale exponentially with the maximum number of closely-spaced objects, is needed to arrive at the correct solution. To address the computational challenge, we recently presented a theoretical translation of this brute force approach to an adiabatic quantum annealer (Tran, el al 2014) with resource requirements that do not depend on the number of objects. However, a realistic CSO resolution problem imposes resource constraints that are beyond the limits of the D-Wave, a commercially available quantum annealer.

In this research, we present a simplified CSO resolution problem, which requires fewer resources: the multi-path time-delay problem, i.e., the resolution of multiple copies of a single signal that reach the receiver via slightly different paths. We also present experimental results of the algorithm's performance on the D-Wave architecture. This research effort provides evidence that a real-world problem can be solved using a quantum annealer.

9500-12, Session 2

Complementary imaging with compressive sensing

Gregory A. Howland, Air Force Research Lab. (United States) and Univ. of Rochester (United States); John C. Howell, James Schneeloch, Daniel Lum, Univ. of Rochester (United States)

A current trend in quantum sensing and imaging is a move away from strong, projective measurements typically associated with wavefunction collapse. One compelling example is compressive sensing, which compresses a signal during measurement to require far fewer measurements than a basis-scan. This offers a powerful tool for scaling quantum measurements to many dimensions. In this talk we will show how compressive sensing also has more fundamental implications for quantum measurement---particularly as it relates to the uncertainty principle.

Compressive sensing is a measurement technique that uses optimization to recover an n-dimensional compressible signal from a dramatically undersampled set of m<< n random, linear projections. For imaging, these projections often take the form of random, binary filters followed by a single-element detector. This system is referred to as a single-pixel camera.

Each filtering operation maps a small amount of position information onto the total flux passing the filter. Because only a small amount of information is extracted, the disturbance to the state is small and momentum distribution is left intact up to a small noise floor. This is best understood by the entropic formulation of the uncertainty principle---the more information a measurement provides about a quantum system's position statistics, the less information a subsequent measurement can provide about the system's momentum statistics. Importantly, this does not specify the manner in which momentum information must be lost. We extract position information at the cost of noise, not the usual blurring associated with projective measurements.

Using our technique, we efficiently recover high resolution transverse-position and transverse-momentum distributions (the image and diffraction pattern) of an unknown optical field from a single-set of measurements. We first image the field onto a sequence of random patterns. After the pattern, the light is collected with a CCD placed in the focal (momentum) plane of Fourier-transforming lens. The momentum distribution is imaged directly on the CCD, while compressive sensing algorithms are used to recover the position distribution. Images/Diffraction patterns imaged include double-slit and triple-slit patterns, an hbar character, and the University of Rochester logo.

We strongly emphasize that we do not violate any uncertainty relations---rather we carefully choose our measurements to economize the use of information we obtain.

The results to be presented in this talk can be found in our recent Physical Review Letter: "Simultaneous Measurement of Complementary Observables with Compressive Sensing" Phys. Rev. Lett. 112, 253602

9500-13, Session 2

Sensors based on quantum hyper-entanglement: efficiency and performance in the presence of other photon sources

James F. Smith III, U.S. Naval Research Lab. (United States)

Sensors based on quantum hyper-entanglement that can act alone or in a group to form an array are analyzed. Sources of interference that can be hyper-entangled, entangled, non-entangled or completely of a random nature are included in the analysis. Like the sensors, the sources of interference can form arrays. Improvements in the transmitter and detector designs are discussed resulting in new closed form expressions that are a function of the design and parameters of the sensor arrays, the interference sources and the environment. These parameters include coherence times, aperture diameters, atmospheric loss, target areas, etc. New closed form expressions include performance measures that are explicit functions of sensor properties, e.g. the number of modes d used for hyper-entanglement, the number of transmitters and detectors denoted as M used by an array, mode properties, e.g. polarization, and energy-time for both the sensor and the interference sources. They are also explicit functions of environmental properties, e.g. loss and noise parameters. These measures include: the probability of detection, various coincidence probabilities, signal to noise or interference ratios, the quantum Fisher information, the quantum Chernoff bound, and estimates of the number of measurements required. The sensors make use of one signal and one ancilla photon at optical or infrared frequencies. Only the signal photon propagates in the atmosphere. This results in loss being essentially classical, giving rise to stronger forms of entanglement. Hyper-entanglement and array formation greatly improves signal to noise or interference ratios, system range, angle measurement errors, and measurement time.

9500-14, Session 2

Finding analytical solution for mirror inverse gate operations in quantum systems with diagonal interactions

Rudrayya C. Garigipati, Preethika Kumar, Wichita State Univ. (United States)

In this paper, we present an analytical solution for implementing mirror inverse (MI) gate operations in quantum systems with diagonal (Ising type) interactions. Unlike non-diagonal XY interactions where a SWAP gate is easily implemented, in Ising coupled systems, each swap operation needs to be decomposed into 3 controlled-NOT (CNOT) gates. As such, methods for finding system parameters that allow us to transmit qubit states along LNN arrays without requiring swap gates can greatly reduce the overall computational overhead in these systems. In our recent work, we showed that MI gate operations can be implemented directly in Ising coupled systems without having to decompose the operation into a sequence of CNOT gate operations. To achieve this we use a dynamic learning algorithm as a tool, for finding parameters of the Ising-coupled system Hamiltonian that realizes the operation. Here, we first choose a Hamiltonian, and then train its parameters to implement the desired MI gate operation within a chosen time duration (T). Once the parameter values are known, we simply set the system parameters to the values solved for, and then allow the system to evolve for time T. However, as the number of qubits increases, the number of system parameters also increase, which makes the training process complex. However, by carefully analyzing the parameter values obtained from training systems with fewer qubits, we try to find analytical solutions that can be extended to calculate parameter values to achieve MI in systems with large number of qubits without the need for training.

9500-15, Session 3

Chip-scale quantum communications *(Invited Paper)*

Ryan M. Camacho, Paul S. Davids, Christopher T. DeRose, Mohan Sarovar, Junji Urayama, Sandia National Labs. (United States)

Future scalable quantum communications technologies will require new tools and devices at the micro-scale that can generate, process, and detect photons for quantum signal processing. While nano- and micro-photonic devices are now routinely used for classical communications processing, significant challenges still remain for accomplishing quantum communication tasks in scalable systems. In this talk, I will give an overview of our team's efforts to overcome some of these bottlenecks and discuss progress towards the construction of a chip-scale quantum transceiver for QKD.

9500-16, Session 3

Quantum networks of trapped atomic ions *(Invited Paper)*

Christopher Monroe, Univ. of Maryland, College Park (United States)

Laser-cooled and trapped atomic ions are standards for quantum information science, acting as qubits with unsurpassed levels of quantum coherence while also allowing near-perfect measurement. When qubit state-dependent optical forces are applied to a collection of atomic ions, their Coulomb interaction is modulated in a way that allows the entanglement of the qubits through quantum gates that can form the basis of a quantum computer. Similar forces allow the simulation of quantum magnetic interactions, and recent experiments have implemented tunable long-range interacting spin models with up to 20 trapped ions, the largest collection of interacting qubits yet demonstrated. Scaling to even larger numbers can be accomplished by coupling trapped ion qubits to optical photons, where entanglement can be formed over remote distances for applications in quantum communication, quantum teleportation, and distributed quantum computation. By employing such a modular and reconfigurable architecture, it should be possible to scale up ion trap quantum networks to useful dimensions, for future applications in quantum computing and quantum communication that are impossible using classical processors.

9500-17, Session 3

Targeted single qubit gates with neutral atoms in a 3D optical lattice

David S. Weiss, Yang Wang, Aishwarya Kumar, The Pennsylvania State Univ. (United States)

We have demonstrated arbitrary single qubit gates on single atoms at targeted sites in a 5x5x5 optical lattice array. Targeted atoms see a pair of orthogonal Stark-shifting addressing beams that selectively shift their microwave resonance frequencies. The targeted atoms are transferred from the qubit storage basis to a computational basis, in which arbitrary Bloch sphere rotations can be performed. They are then returned to the storage basis, and a new target is selected. These operations have a negligible effect on non-targeted atoms. The addressing beams can be redirected by microelectromechanical systems (MEMS) mirrors in 5 microseconds. Gate operations take ~200 microseconds and coherence times exceed 5 s. Arbitrary targeted single qubit gates are an important step along the path of making a neutral atom quantum computer in a highly scalable geometry. In the future, arbitrary sorting of atoms among lattice sites and scalable pairwise entanglement will be pursued.

9500-18, Session 3

Towards scalable quantum information processing with cold atoms and Rydberg blockade

Mark E. Saffman, Tian Xia, Martin Lichtman, Kara Maller, Yuan Sun, Univ. of Wisconsin-Madison (United States)

We are exploring several different approaches towards scalable quantum computing based on neutral atom qubits with long range Rydberg blockade. Rydberg interactions can be used to entangle single atom qubits, to entangle ensemble qubits, and to establish hybrid entanglement between atomic and other qubits. Using a 2D array of atomic qubits we demonstrate high fidelity single qubit control together with entanglement of nearby qubits. The ratio of qubit coherence time to entangling gate time exceeds 1000. Progress towards hybrid atom-superconductor entanglement via a microwave mediated controlled phase gate will also be presented.

9500-19, Session 3

Scalable quantum computing architecture with mixed species ion chains

Boris Blinov, John Wright, Tomasz Sakrejda, Richard Graham, Zichao Zhou, Carolyn Auchter, Thomas Noel, Univ. of Washington (United States)

We describe our work on implementing mixed ion species quantum information processing for a scalable ion trap architecture. These mixed species chains may help solve several problems with scaling ion trap quantum computation to large numbers of qubits. In the MUSIQC architecture [1], an expandable number of Elementary Logic Units (ELUs), microfabricated traps holding linear chains of 10 to 100 ions, are linked together using a photonic interface to form a large-scale system. Local quantum gates are performed using motional coupling between ions in the same trap. Few ions in each chain are reserved for performing a slower entanglement operation between ions in different ion traps coupled by optical fibers. This long distance entanglement will be accomplished using photon-mediated ion-ion entanglement, in which pairs of ions are projected into an entangled Bell state by a combined measurement of their emitted single photons [2]. We intend to separate the fast motional coupling and the slower remote ion entanglement to different ion species, barium and ytterbium respectively, whose atomic transitions are widely separated in frequency, yet atomic masses are relatively similar. Remote entanglement generation and laser cooling ions of one species (Ba) then will not cause decoherence in ions of the other species (Yb).

1. C. Monroe, R. Raussendorf, A. Ruthven, K. R. Brown, P. Maunz, L.-M. Duan, and J. Kim. Large-scale modular quantum-computer architecture with atomic memory and photonic interconnects. Phys. Rev. A 89, 022317 (2014).

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9500-20, Session 3

High fidelity quantum information processing in surface ion traps

Jungsang Kim, Emily Mount, Daniel Gaultney, Stephen Crain, Geert Vrijsen, Duke Univ. (United States)

Trapped ions provide one of the most robust platforms for realizing quantum computation and quantum networks, due to the long qubit coherence times and high fidelity qubit operations that have been demonstrated, such as qubit initialization, measurement, and quantum logic gates. In addition, feasibility for practical quantum networking has been demonstrated in this platform by generating remote ion-ion entanglement using two ion-photon entangled pairs. The main hurdle towards scalable quantum information processors with ion traps is a viable path to technological scalability, where large numbers of ion qubits and their corresponding control signals can be integrated into a single system within a compact package. Surface traps fabricated on silicon substrates using microfabrication techniques allow us to build multi-zone ion traps where large numbers of ions can be trapped and their motion can be controlled. Design of high quality optical components and micromirror-based beam delivery systems allow one to provide stable laser beams that can be adequately steered to perform individually-addressed quantum logic gates on a chain of ions in these surface traps. Careful choice of ion-photon entanglement scheme enables generation of ion-ion entangled pairs between two ions trapped in two independent traps at rates fast compared to decoherence times of the ion qubits. These experimental primitives can be combined to construct a truly scalable quantum information processor with reconfigurable connectivity among the qubits in the system. In this work, we will discuss the high speed, high fidelity qubit measurement and high fidelity single qubit gates implemented in surface traps using laser beams generated by a frequency comb. We will also discuss the progress towards high fidelity two-qubit gates in surface traps, and high-rate entanglement generation between two surface traps installed in two independent vacuum chambers. These experiments demonstrate a concrete implementation of modular, scalable ion trap quantum computer.

9500-21, Session 4

Superconducting metamaterials and qubits

Britton L. T. Plourde, Haozhi Wang, Francisco Rouxinol, Matthew LaHaye, Syracuse Univ. (United States)

We will report on the fabrication of a variety of superconducting thin-film metamaterial resonators and our characterization of their transmission spectra at low temperatures. In parallel, we have performed various numerical simulations of these structures to compare with our measured spectra and to investigate the standing-wave patterns of the various modes. We will describe how we can couple a transmon qubit to these metamaterial resonators and discuss possible future investigations, including the generation of multi-mode entanglement, with this system.

9500-22, Session 4

An optimal fusion transformation for cluster state growth using only linear optical elements

Dmitry B. Uskov, Brescia Univ. (United States); Pavel Lougovski, Oak Ridge National Lab. (United States); Paul M. Alsing, Michael L. Fanto, Air Force Research Lab. (United States); Lev Kaplan, Tulane Univ. (United States); Amos M. Smith, Oak Ridge National Lab. (United States)

We analyze the generation of linear optical cluster states (LOCS) by sequential addition of one and two qubits. While it is known that 1/9 is the maximal for the CZ gate the question of whether the CZ gate itself is the optimal operation state remains open. We find that the optimal cluster growth operation is a state transformation on a subspace of the full Hilbert space and requires no additional resources. We show the maximal success rate of fusing n photonic qubits or m Bell pairs is (1=2)^n-1 and (1=4)^m-1. We give an explicit that implements this fusion transformation.

9500-23, Session 4

Functional role of tunneling in a programmable quantum annealer

Vadim N. Smelyanskiy, NASA Ames Research Ctr. (United States)

We present first experimental evidence of a computational role of multi-qubit quantum tunneling in the evolution of a programmable quantum annealer. We developed a theoretical model of multi-qubit dissipative co-tunneling under the complex noise characteristics based on a Polaronic Quantum Master Equation. We considered a non-convex optimization primitive realized by frustrated network of qubit clusters with strong intra-cluster coupling. We analyze a particular example with sixteen qubits, demonstrating eight qubit co-tunneling that increases success probabilities compare to classical paths. We report results for larger problems with up to 200 qubits that contain the primitive as subproblems.

9500-24, Session 4

Induced dipole-dipole forbidden transitions in rare-earth elements and their prospects for quantum information processing

Eric Donkor, Ryan Williams, Fahad A. Althowibi, Univ. of Connecticut (United States)

In this paper we discuss the prospects of quantum information processing based on forbidden transitions in the inner shell of the rare-earth elements. We shall derive the selection rule for such transitions and investigate the prospects for rare-earth based quantum information procession emphasizing their long decoherence time, degree of entanglement, and lossless interconnectivity.

9500-25, Session 5

How often must we apply syndrome measurements?

Yaakov S. Weinstein, The MITRE Corp. (United States)

Correcting errors is a vital but expensive component of fault tolerant

quantum computation. Standard fault tolerant protocol assumes that attempted detection of errors via syndrome measurements is done after every quantum gate. In fact, this is not necessary. In this talk I demonstrate that error correction should be applied more sparingly. This is achieved by simulating encoded single-qubit rotations within the [[7,1,3]] code and showing, via fidelity measures, that applying error correction after every gate is not desirable.

9500-26, Session 5

Random multipartite correlations measure pure multipartite entanglement

Minh C. Tran, Nanyang Technological Univ. (Singapore); Tomasz Paterek, Nanyang Technological Univ. (Singapore) and Ctr. for Quantum Technologies (Singapore); Wieslaw Laskowski, Univ. Gdanski (Poland); Francois Arnault, Univ. de Limoges (France); Borivoje Dakic, Vienna Ctr. for Quantum Science and Technology (Austria) and Univ. Wien (Austria)

Entanglement is one of the basic features of quantum physics and it is a resource for quantum information science [1]. Its detection and characterization belong to the mainstream of this field but we still lack a complete understanding of this phenomenon, especially for the multipartite case. Recently there have been results concerning entanglement identification and quantification of multipartite systems which involve sequence of specific measurements of the quantum states [2-4] and thus strictly require communication between the laboratories during the measurements.

In this paper we shall present a different technique to identify and quantify entanglement that requires no such sequence. Each local subsystem can be measured randomly and independently from each other and only after that will the correlations between all parties, which contain knowledge about entanglement of the system, be computed. Therefore it is possible that no communication between the parties is needed until all the measurements have been carried out.

We shall show that the expectation of these squared random correlations is proportional to the sum of squared correlations in a complete set of orthogonal basis. This allows us, using two copies of the quantum state, to prove a lower bound on the random correlations. Interestingly the lower bound is achieved only by product states and thus makes the random correlations a legitimate entanglement identifier. Although the same statement about the sum of squared correlations is already present in the works of Hassan and Joag [6,7], their mathematical proof is based on an earlier incorrect theorem [5]. Nevertheless, it follows from their works that the sum of squared correlations actually measures entanglement, and therefore so do our random correlations. We show what is the maximal allowed entanglement according to this measure and proved for odd systems that it is achieved by Greenberger-Horne-Zeilinger states. Next, we use convex roof construction to extend the measure to mixed states, derive a computable formula for entanglement of any rank-two states, and illustrate it on an example. A derivation similar in spirit was presented by Osborne for the measure called I-tangle [8]. Finally, we would like to emphasize that the proofs here can be generalized to qudits and in fact hold for arbitrary states independently of dimensionality and the number of subsystems.

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9500-27, Session 5

Measuring arbitrarily accurate pulse compensation with randomized benchmarking

True Merrill, Georgia Tech Research Institute (United States); Chingiz Kabytayev, Georgia Institute of Technology (United States); Adam Meier, Georgia Tech Research Institute (United States); Kenneth R. Brown, Georgia Institute of Technology (United States)

We study a method to determine the fidelity scaling behavior of compensating pulse sequences with respect to control calibration errors. Sequences that compensate control error to arbitrary order are known, but testing their performance in an experiment is challenging when the residual control error is less than state preparation and measurement (SPAM) errors. However, a randomized benchmarking (RB) protocol can be used to estimate the sequence fidelity independent of SPAM errors. We derive the analytic fidelity response with respect to amplitude errors for arbitrary compensating sequences in a RB protocol. Single- and multi-qubit compensating sequences are considered. These results are compared in a numerical study that simulates RB measurements with realistic SPAM errors in 171Yb+ ion qubits.

9500-28, Session 5

Demonstrating continuous variable Einstein-Podolsky-Rosen steering with a finite number of measurements

James Schneeloch, Samuel Knarr, Gregory A. Howland, John C. Howell, Univ. of Rochester (United States)

We show how one can demonstrate continuous-variable EPR-steering without needing to characterize entire joint measurement probability distributions. To do this, we develop a modified Fano inequality useful for bounding the conditional entropies of continuous variables. This is an important development, as the ordinary Fano inequality gives a bound, which up to a contstant offset, is proportional to the logarithm of the (infinite) number of possible outcomes. Using only the very broad statistical assumption that the expectation value of the marginal position or momentum is finite, we provide a (much) tighter bound to the conditional entropy. Next, we use the modified Fano inequality in a continuous variable entropic EPR-steering inequality to demonstrate EPR-steering using only enough information to characterize the bound. Because Fano's inequality requires knowledge of only the diagonal elements of a joint probability distribution, it is a substantial improvement to the number of measurements needed to demonstrate EPR-steering. In addition, these bounds allow us to easily hedge against experimental limitations including a finite detector size, dead space between pixels, less than perfect detection efficiencies, and any such factors that impose an incomplete sampling of the true measurement probability distribution. Because of this, one can now reliably demonstrate EPR-steering in continuous variables without having to make the simplifying but unrealistic assumption that the detector is collecting 100 percent of the light emitted from the entangled source. These Fano steering bounds are particularly effective for highly correlated probability distributions, such as the joint position and momentum distributions of photon pairs emitted in spontaneous parametric downconversion. Furthermore, we provide evidence that this method is sufficiently sensitive for practical use.

9500-29, Session 5

Considerations on the collapse of the wave function

John F. Reintjes, Sotera Defense Solutions (United States); Mark Bashkansky, U.S. Naval Research Lab. (United States)

Collapse of the wavefunction plays a central role in the theory of quantum measurement, and has been discussed extensively in the literature. Wavefunction collapse has also been discussed in the context of state preparation in which the measurement of one component of an entangled pair projects the remaining (unmeasured) component into an un-entangled single particle quantum state that depends on the result of the measurement [1] Conceptual issues remain with respect to collapse, or reduction, of the wavefunction as to whether it represents a physical process or is just a mathematical concept. In this work, we discuss features of the collapse of the wavefunction (or equivalently, for our purposes, projection of the quantum state) within the context of state preparation using entangled signal-idler photon pairs from a spontaneous parametric downconversion (SPDC) source in the entangled ghost imaging configuration. Specifically, we examine the form that the quantum state of the signal can take following an idler measurement, and calculate its propagation properties from the ghost image plane to a downstream diffraction plane. We investigate the extent to which the predictions of propagation properties using different collapse models agree with the predictions of non-collapse models. Our results demonstrate that agreement between collapse and non-collapse models can be obtained if the signal is assumed to collapse into a specific mixed state. However, measurable distinctions between collapse and non-collapse models are predicted to arise if the signal is modeled to collapse into a pure state.

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9500-31, Session 6

Diagrammatic quantum mechanics

Louis H. Kauffman, Univ. of Illinois at Chicago (United States); Samuel J. Lomonaco Jr., Univ. of Maryland, Baltimore County (United States)

Quantum mechanics can be described, particularly for working with quantum information and topological quantum computing in the following short form: Physical states are in correspondence with unity vectors in a Hilbert space (often taken to be finite dimensional). Physical processes are in correspondence with unitary transformations of the Hilbert space. Measurements can be described with respect to an orthonormal measurement basis of the Hilbert space so that each basis element corresponds to a possible outcome of the measurement. The probability of an outcome is equal to the absolute square of its inner product with the given physical state. By using this concise model of quantum mechanics we can describe quantum algorithms and quantum processes. A process consisting in a composition of unitary transformations is susceptible to a number of diagramming techniques - circuit diagrams, graphs, semi-realistic interaction descriptions, explications in terms of category theory, relationships with topological diagrams such as knot and link diagrams and structures from topological quantum field theory. It is the purpose of this talk to give a unified treatment of these diagrammatic modes of representation of quantum mechanics.

In particular, we show how the diagrammatic approach leads naturally to a discrete version of the path integral formulation of quantum mechanics, and we show how when one goes to the continuum limit of discrete models, the actual path integral formalism appears naturally. In this limiting situation we see that the set of outcomes of a measurement is usually conflated with a set of spatial locations. These locations are nodes in the graphs for our discrete approach and we see how the topology of the limit space is now tightly related to the structure of the resulting quantum mechanics. This gives rise to a discussion of the relationship of physical space and the properties of quantum theory. In particular we will discuss non-locality in this context and we will use specific models to illuminate the principles (for example the Feynman Checkerboard Model for the Dirac propagator is quite useful in this regard).

9500-32, Session 6

Principal fiber bundle description of number scaling for scalars and vectors: application to gauge theory

Paul Benioff, Argonne National Lab. (United States)

The fiber bundle approach to effects of number scaling in physics and geometry will be described. A big advantage of this approach is that it allows a clear distinction between local mathematical structures as contents of individual fibers and global mathematical structures whose elements represent connections between different fibers. Each fiber contains a finite dimensional vector space and a complex scalar field for gauge theories or a real scalar field for tangent spaces in geometry. The manifold is assumed to be flat space time. For gauge theories there is an associated principal frame bundle with U(n) connections between the frame fibers.

Connections due to number scaling are described by a complex vector field for gauge theories and a real field for tangent bundles. In both cases the real vector field is assumed to be integrable. The imaginary part is non integrable if it is the photon field. For gauge theories, properties of the complex field will be summarized. The use of the Higgs mechanism to assign mass to the real and imaginary components of the connection field will be described. For tangent bundles the effect of the fields on curve lengths and on geodesic equations will be noted.

9500-33, Session 6

Consequences of recognizing unpredictability beyond quantum uncertainty

John M. Myers, Harvard Univ. (United States); Frederick H. Madjid, Consultant (United States)

Quantum uncertainty denotes a spread of a probability measure on a set of possible outcomes. Over the history of physics, many advances, including the introduction of quantum mechanics, have come as new possibilities, for which no probability was assigned prior to their arrival. Within quantum theory, recent work has proven cases of essential unpredictability beyond the probabilistic uncertainty of quantum mechanics. An example is the choosing of a wave function to explain given evidence. Recognizing essential unpredictability impacts the application of physical concepts by recognizing a tree structure of assumptions, by showing the breakdown of the concept of time in general relativity, and by recognizing the dependence of measurement units on assumed equations, leading to the avoidance of concepts unnecessary to a particular endeavor, replacing them by more direct comparisons.

9500-34, Session 6

Topological and geometrical quantum computation in cohesive Khovanov homotopy type theory

Juan F. Ospina, Univ. EAFIT (Colombia)

The recently proposed Cohesive Homotopy Type Theory is exploited as a formal foundation for central concepts in Topological and Geometrical Quantum Computation. Specifically the Cohesive Homotopy Type Theory provides a formal, logical approach to concepts like smoothness, cohomology and Khovanov homology; and such approach permits to clarify

the quantum algorithms in the context of Topological and Geometrical Quantum Computation. In particular we consider the so-called "open-closed stringy topological quantum computer" which is a theoretical topological quantum computer that employs a system of open-closed strings whose worldsheets are open-closed cobordisms. The open-closed stringy topological computer is able to compute the Khovanov homology for tangles and for hence it is a universal quantum computer given than any quantum computation is reduced to an instance of computation of the Khovanov homology for tangles. The universal algebra in this case is the Frobenius Algebra and the possible open-closed stringy topological quantum computers are forming a symmetric monoidal category which is equivalent to the category of knowledgeable Frobenius algebras. Then the mathematical design of an open-closed stringy topological quantum computer is involved with computations and theorem proving for generalized Frobenius algebras. Such computations and theorem proving can be performed automatically using the Automated Theorem Provers with the TPTP language and the SMT-solver Z3 with the SMT-LIB language. Some examples of application of ATPs and SMT-solvers in the mathematical setup of an open-closed stringy topological quantum computer will be provided..

9500-35, Session 6

Heterotic quantum and classical computing on a convergence space architecture

Howard A. Blair, Daniel R. Patten, Robert J. Irwin, David W. Jakel, Syracuse Univ. (United States)

Category-theoretic characterizations of heterotic models of computation, introduced by Stepney et al., combine computational models such as classical/quantum, digital/analog, synchronous/asynchronous, etc. to obtain increased computational power. A highly informative classical/quantum heterotic model of computation is represented by Abramsky's simple sequential imperative quantum programming language which extends the classical simple imperative programming language to encompass quantum computation. The mathematical (denotational) semantics of this classical language serves as a basic foundation upon which formal verification methods can be developed. We present a more comprehensive heterotic classical/quantum model of computation based on heterotic dynamical systems on convergence spaces.

Convergence spaces subsume topological spaces but admit finer structure from which, in prior work, we obtained differential calculi in the cartesian closed category of convergence spaces allowing us to define heterotic dynamical systems, given by coupled systems of first order differential equations whose variables are functions from the reals to convergence spaces.

To capture probabilistic nondeterministic operations such as occur in Abramsky's language, we require "multi-valued functions" that return values probabilistically from a finite set of possibilities. A unitary operation U on quantum registers is implemented by having the right-hand side of the differential equation governing the register produce the unitary operator. Convergence spaces subsume topological spaces but admit finer structure, which we previously used to obtain differential calculi in the cartesian closed category of convergence spaces.

Finally, we introduce several specific questions for future research concerning the general conditions for constructing a separable Hilbert space of complex-valued mappings on convergence spaces.

9500-36, Session 6

Quantum probabilistic logic programming

Radhakrishnan Balu, U.S. Army Research Lab. (United States)

We describe a logic programming language that supports Horn clauses, random variables, and covariance matrices to express and solve problems in probabilistic logic. The Horn clauses of the language wrap random variables and matrices to express probability distributions and statistical correlations, a powerful way to capture relationship between identical distributions that are not independent. A salient feature of the language is a mechanism to implement statistical ensembles and to solve the underlying SAT instances of probabilistic predicates using quantum mechanical machinery. We exploit the fact that classical random variables have quantum decompositions to build the quantum mechanical observables. We establish the semantics of the language in a rigorous fashion by considering an existing probabilistic logic language called PRISM with classical probability measures defined on the Herbrand base and extend it to the case of quantum probability. In the classical case H-interpretations form the sample space and probability measures defined on them lead to consistent definition of probabilities for well formed formulae. In the quantum analogue probability amplitudes are attached to H-interpretations facilitating the model generations and verifications via quantum mechanical superpositions and entanglements. The well formed formulae of the language can be cast as quantum mechanical observables and thus providing an elegant interpretation for their probabilities. We discuss several examples to combine statistical ensembles and predicates of first order logic to reason with situations involving uncertainty. We provide comments on possible implementation issues one may encounter on different quantum hardware considered in the literature.

9500-37, Session 6

Theoretical analysis of on-chip linear quantum optical information processing networks

Stefan F. Preble, Jeffrey A. Steidle, Edwin E. Hach III, Rochester Institute of Technology (United States)

We present a quantum optical analysis of waveguides directionally coupled to ring resonators, an architecture realizable using silicon nanophotonics. The innate scalability of the silicon platform allows for the possibility of "on-chip" quantum computation and information processing. In this paper, we briefly review a comprehensive method for analyzing the quantum mechanical output of such a network for an arbitrary input state of the quantized, traveling electromagnetic field in the continuous wave (cw) limit. Next, we generalize the simple cw model to properly account for the effects of pulsed, multi-mode operation. In particular, we propose and analyze a scalable, on-chip realization of the Nonlinear Sign (NS) shifter essential for implementation of the Knill-Laflamme-Milburn (KLM) protocol for Linear Optical Quantum Computing (LOQC). Finally, we discuss generalizations to arbitrary networks of directionally coupled ring resonators along with possible applications is the areas of quantum metrology and sensitive photon detection. In connection with these broad applications, we discuss the possibilities for on-chip versions of intriguing experiments in quantum optics that, so far, have been performed only in bulk optics. Specifically, we will demonstrate how a particular device topology yields, via Passive Quantum Optical Feedback (PQOF), dramatic and unexpected enhancements of the Hong-Ou-Mandel Effect, an effect central to the operation of many quantum information processing systems.

9500-38, Session 6

Geometric topological circuit diagrams for adiabatic quantum computation

Avishy Carmi, Ben-Gurion Univ. of the Negev (Israel); Daniel Moskovich, Tomasz Paterek, Nanyang Technological Univ. (Singapore)

In adiabatic quantum computing (AQC) , a prepared Hamiltonian (the initial Hamiltonian) evolves towards a Hamiltonian (the terminal Hamiltonian) whose ground state encodes the solution to the problem of interest. While AQC is known to be equivalent to the quantum circuit model its physical

characteristics entail different design principles for quantum algorithms. We propose a formalism to decompose adiabatic quantum computations into component substeps. The resulting diagrammatic algebraic structures are reminiscent of coloured tangle diagrams in low dimensional topology. We argue that our formalism offers the following advantages:

• It captures conservation laws of quantum information. In particular, it captures no-cloning. Inside our formalism, we show that that the input Hamiltonian cannot be copied during the computation. We can also quantify the fidelity of any imperfect cloning described in our diagrams.

• Component computations use deformed (rescaled) time parameters. In the limit our diagrams represent sequential computations. In this sense our diagrams may be considered as AQC analogs to circuit diagrams.

• The terminal Hamiltonian is designed using the problem logic. In our formalism we may construct it by embedding individual clauses as subcomputations.

• Our diagrams facilitate error detection and correction by identifying problematic substeps.

• Our decompositions of adiabatic quantum computations are not unique, and different diagrams represent equivalent computations with different performance parameters.

We illustrate the utility of our formalism by adiabatically realizing some known quantum algorithms, including a 2-SAT problem and a quantum Fourier transform.

9500-59, Session 6

Staged quantum energy teleportation

Michael R Frey, Bucknell University (United States)

Standard quantum energy teleportation (QET) is a protocol facilitated by a coupled particle pair for a sender, Alice, to transfer energy to a receiver, Bob. In the standard QET protocol Alice makes a local quantum measurement of her particle, thereby injecting energy into the particle pair. She communicates the measurement result to Bob, who then applies a local unitary transformation in accordance with Alice's communication, successfully extracting energy from his particle. A variant of the standard QET protocol is proposed in which energy transfer occurs in stages. In each stage Alice makes a weak measurement of her particle, she communicates the result to Bob, and Bob operates on his particle accordingly to successfully extract energy. Weak measurements allow multiple transfers of energy via the same particle pair, with both greater overall efficiency and greater total energy throughput. Two-stage QET is shown for a particular spin-1/2 particle pair to increase throughput by 35% and efficiency by 25% over standard QET.

9500-49, Session PThu

Quantum random number generation algorithm realized by smartphone camera

Nan Wu, Kun Wang, Haixing Hu, Fangmin Song, Nanjing Univ. (China); Xiangdong Li, The City Univ. of New York (United States)

We propose and study an efficient algorithm that extracts quantum random numbers (QRN) from the raw data of CCD- or CMOS- based image sensors (cameras) in commercial smartphones. Based on NIST statistical test on random number generators, the proposed algorithm can give good performance in QRN generation rate and with a higher statistical randomness. This algorithm can be implemented to provide simple-structure, low-price and reliable QRN devices for QKD or other cryptographic applications.

9500-50, Session PThu

Absorption problems for three-state quantum walks

Kun Wang, Haixing Hu, Nan Wu, Fangmin Song, Nanjing Univ. (China); Xiangdong Li, The City Univ. of New York (United States)

In this paper we study the behavior of three-state discrete quantum walks. In particular, we present results for absorption probabilities in the systems with one or two absorbing boundaries for one-dimension problem. A combinatorial expression for these probabilities is presented by using the path integral method. We show that the behavior of three-state quantum walks is strikingly different from classical random walk.

9500-52, Session PThu

Calculation of key reduction for B92 QKD protocol

Miralem Mehic, Pavol Partila, Jaromir Tovarek, Miroslav Voznak, V?B-Technical Univ. of Ostrava (Czech Republic)

It is well known that Quantum Key Distribution (QKD) can be used with highest level of security for distribution of secret key, which is further used for symmetrical encryption. B92 is one of the oldest QKD protocols. It uses only two non-orthogonal states, each one coding for one bit-value. It is much faster and simpler when compared to its predecessors, but with the idealized maximum efficiencies of 25% over the quantum channel. B92 consists of several phases in which initial key is significantly reduced: secret key exchange, extraction of the raw key (sifting), error rate estimation, key reconciliation and privacy amplification. QKD communication is performed over two channels: the quantum channel and the classical public channel. In order to prevent man-in-the-middle attack and modification of messages on the public channel, authentication of exchanged values must be performed. We used Wegman-Carter authentication, because it describes an upper bound for needed symmetric authentication key.

We explained the reduction of the initial key in each of QKD phases. Also, we presented the equation which can be used for calculation of the length of the final key, based on parameter "level of security" and quantum bit error rate (QBER) in the quantum channel. Intensive testing with Quantum Cryptography simulator confirmed proposed equation. The results of experiments are included in the paper.

9500-39, Session 7

A bright PPKTP waveguide source of polarization entangled photons

Michael L. Fanto, Air Force Research Lab. (United States); Christopher C. Tison, Rome Research Corp. (United States) and Florida Atlantic Univ. (United States); Stefan F. Preble, Rochester Institute of Technology (United States); Paul M. Alsing, Air Force Research Lab. (United States)

The need for bright efficient sources of entangled photons has been a subject of tremendous research over the last decade. Researchers have been working to increase the brightness and purity to help overcome the spontaneous nature of the sources. Periodic poling has been implemented to allow for the use of crystals that would not normally satisfy the phase matching conditions. Utilizing periodic poling and single mode waveguide confinement of the pump field has yielded extremely large effective nonlinearities in sources easily producing millions of photon pairs. Here we will demonstrate these large nonlinearity effects in a periodically poled potassium titanyl phosphate (PPKTP) waveguide as well as characterizing the source purity.

9500-40, Session 7

High spectral purity silicon ring resonator photon-pair source

Stefan F. Preble, Rochester Institute of Technology (United States); Michael L. Fanto, Air Force Research Lab. (United States); Christopher C. Tison, Rome Research Corp. (United States) and Florida Atlantic Univ. (United States); Zihao Wang, Jeffrey A. Steidle, Rochester Institute of Technology (United States); Paul M. Alsing, Air Force Research Lab. (United States)

Here we present the experimental demonstration of a Silicon ring resonator photon-pair source. The crystalline Silicon ring resonator (radius of 17.5um) was designed to realize low dispersion across multiple resonances, which allows for operation with a high quality factor of Q~80k. In turn, the source exhibits very high brightness of >5E7 photons/s/mW^2/GHz since the produced photon pairs have a very narrow bandwidth. Furthermore, the waveguide-fiber coupling loss was minimized to <1.5dB using an inverse tapered waveguide (tip width of ~150nm over a 300um length) that is butt-coupled to a high-NA fiber (Nufern UHNA-7). This ensured minimal loss of photon pairs to the detectors, which enabled very high purity photon pairs with minimal noise, as exhibited by a very high Coincidental-Accidental Ratio of >1300. The low coupling loss (3dB fiber-fiber) also allowed for operation with very low off-chip pump power of <50uW. In addition, the zero dispersion of the ring resonator resulted in the production of a photon-pair comb across multiple resonances symmetric about the pump resonance (every ~5nm spanning >20nm), which could be used in future wavelength division multiplexed quantum networks. Lastly, we present results on using the same source to generate degenerate bi-photons by using two pump lasers operating at symmetric wavelengths. And we discuss a dispersion tailoring approach for producing degenerate bi-photons with ultra-high purity and brightness. Such a source will be able to generate indistinguishable photon pairs for a variety of quantum information applications.

9500-41, Session 7

High heralding-efficiency of near-IR fiber coupled photon pairs for quantum technologies

P. Ben Dixon, Danna Rosenberg, Matthew E. Grein, MIT Lincoln Lab. (United States); Ryan S. Bennink, Oak Ridge National Lab. (United States); Veronika Stelmakh, Franco N. C. Wong, Massachusetts Institute of Technology (United States)

We report on the development and use of a high heralding-efficiency, single-mode-fiber coupled telecom-band source of entangled photons for quantum technology applications. The source generates entangled photon pairs through spontaneous parametric down-conversion (SPDC) in a periodically-poled potassium triphosphate (PPKTP) crystal.

The source development efforts consisted of theoretical and experimental efforts. The theoretical treatment defined the correlated-mode coupling efficiency, an inherent source efficiency related to heralding efficiency. The experimental effort consisted of a systematic study of correlated-mode coupling efficiency and generation rate capabilities using a reconfigurable computer controlled pump-beam and collection-mode optical apparatus with a linearly configured PPKTP source. The measured data agree well with theory and we demonstrated a correlated-mode coupling efficiency of 97% +/- 2%, which is the highest efficiency yet achieved for this type of system. These results confirm that very high overall heralding efficiencies can, in principle, be achieved in quantum optical systems.

We then incorporated these beneficial source development techniques in a Sagnac configured telecom-band entangled photon source that is capable of generating single-mode optical fiber couple photon pairs that are entangled in both time/energy and polarization degrees of freedom. We made use of these highly desirable entangled states to develop and investigate device independent quantum cryptography applications as well as linear optical quantum computing developments.

This work is sponsored by the Assistant Secretary of Defense for Research and Engineering under Air Force contract #FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations

9500-42, Session 7

Parametric down conversion with a depleted pump and its relationship to the black hole information loss problem

Paul M. Alsing, Air Force Research Lab. (United States)

In this paper we extended the well-known analogy of Hawking radiation to the quantum optical process of spontaneous down conversion (SPDC), which is used ubiquitously in photon-based quantum information processing, by exploring the case where the black hole (BH) is analogous to the laser `pump source. That is, we investigate the case of parametric down conversion with a depleted laser pump (vs. undepleted pump - as is typical in laboratory experiments) as a model for BH particle creation and evaporation, and study various features of entanglement in such a system. We discuss how variants of this model might be testable in a tabletop laboratory experiment.

9500-43, Session 7

High-purity single-mode photon source for integrated quantum photonics

Xiyuan Lu, Wei C. Jiang, Jidong Zhang, Qiang Lin, Univ. of Rochester (United States)

Integrated quantum photonics relies critically on the purity, scalability, integrability and flexibility of a photon source to support diverse quantum functionalities on a single chip. Here we report a device on the silicon-on-insulator platform that utilizes dramatic cavity-enhanced four-wave mixing in a high-Q silicon microdisk resonator. The device is able to produce high-purity photon pairs with an unprecedented spectral brightness of 7.01 x10x8 pairs/s/mW2/GHz and a quantum cross-correlation of gsi(2) = (2.58 ± 0.16) x 10^4. The recorded photon correlation violates the classical Schwarz inequality by four orders of magnitude, demonstrating the high purity of the photon pairs. Moreover, the generated photons are single-mode in frequency, time and space, which is proved by the quantum self-correlation gss^(2) and gii^(2), with peak values of 1.86 ± 0.05 and 1.87 ± 0.05, respectively.

We use the high-purity single-mode photon pairs as heralded single-photon source. The conditional photon autocorrelation gc^(2) is as low as 0.0075 ± 0.0017 (0.0026± 0.0006) at 5.9 x 10^4 photon pairs per second, without (with) dark counts subtracted. Even at the rate of 2.9 x 10^6 pairs per second, the conditional photon autocorrelation remains below 0.03, with a heralding efficiency of 78.2%.

The high purity single mode photon-pair/heralded-single-photon source, together with the multi-pair generation, structural compactness, and the CMOS compatibility, opens up a great avenue towards quantum silicon photonics with unprecedented capability of multi-channel parallel information processing for both integrated quantum computing and long-haul quantum communication.

9500-44, Session 8

Coherently stimulated parametric down-conversion in quantum optical metrology

Christopher C. Gerry, Richard Birrittella, Anna Gura, Lehman College (United States)

We examine the properties of the states produced by non-degenerate coherently stimulated parametric down-conversion wherein the signal and idler modes are seeded with coherent states of light and where the nonlinear crystal is driven by a strong classical field as described by the parametric approximation. The states produced at the two-mode squeezed vacuum states defined with a specific ordering of operators, namely the displacement operators of the two modes acting on the double vacuum state followed by the action of the two-mode squeeze operator representing the down-conversion process. Though mathematically equivalent to the reverse ordering of operators, but with different displacement parameters, the ordering we consider is closely related what could most easily be implemented in the laboratory. situation we have in mind corresponds to a specific The statistical properties of the state are studied with an emphasis on how they, and its average photon number, are affected by the various controllable phases, namely that of the classical pump field and those of the two coherent states. We then consider the multi-photon interference effects that arise if the two beams are overlapped on a 50:50 beam splitter, investigating the role of the phases in controlling the statistical properties of the output states. Finally, we study the prospects for the application of the states quantum optical interferometry with great sensitivity than that of the standard quantum limit.

9500-45, Session 8

Properties of antipodal atomic Schrödinger cat states

Christopher C. Gerry, Lehman College (United States); Edwin E. Hach III, Rochester Institute of Technology (United States)

The atomic coherent states are obtained by applying a rotation, with the rotation axis in the x-y plane of the Bloch sphere, on the Dicke state representing the collective ground state of a system of two-level atoms where all atoms are in their ground states. On the other hand, a two-component superposition states is a kind of Schrödinger cat state whose components are antipodal on the Bloch sphere across the north-south axis, a polar cat state. This is a state wherein the atoms are highly entangled and is an atomic form of the Greenberger-Horne-Zeilinger state. We study the states obtained by applying the rotation operator that generates the atomic coherent states to the polar cat state. The transformation rotates the two components such that they remain antipodal and hence remain orthogonal states. In fact, the state is now a superposition of two kinds of atomic coherent states, one generated from the collective atomic ground and the other generated from the collective atomic excited state. We examine the entanglement properties of such states especially in connection with the prospect of there being spin squeezing, a signature of entanglement. We also examine the prospect of employing such states for the purposes of quantum metrology for atomic frequency standards.

9500-46, Session 8

States of photons with space-variant polarization

Enrique J. Galvez, Colgate Univ. (United States); Behzad Khajavi, Colgate Univ. (United States) and Florida Atlantic Univ. (United States); Xinru Cheng, Colgate Univ. (United States) and Univ. of Ottawa (Canada)

We prepare photon pairs in high-dimensional states that are non-separable superpositions of polarization and spatial mode. These states can provide a high-dimensional space in which to encode quantum information.

Our recent study of these states with heralded photons and classical beams have revealed a rich polarization structure in the transverse position basis. We have imaged the transverse mode of the light in these states and found space-variant polarization patterns. These patterns also exhibit optical singularities that had not been studied before in designer beams.

In the laboratory we prepare photon pairs produced via parametric down conversion in non-separable superpositions of polarization and spatial mode. In particular we encode up to three spatial modes using spatial light modulators, which in combination with polarization yield a six-dimensional state of a single photon. We diagnose these states either by quantum tomography or by imaging polarimetry-- a polarization tomography in the transverse-position basis. We also investigate the connection between the quantal and classical state measures.

9500-47, Session 8

Entanglement as a mechanism for controlling distributed quantum systems

Samuel J. Lomonaco Jr., Univ. of Maryland, Baltimore County (United States); Louis H. Kauffman, Univ. of Illinois at Chicago (United States)

We discuss how quantum entanglement can be used to control remote quantum systems. We also discuss how such a control mechanism can naturally be employed through a divide-and-conquer strategy to reducing the effects of decoherence.

9500-48, Session 8

Superconducting circuitry for quantum electromechanical systems

Matthew LaHaye, Francisco Rouxinol , Yu Hao, Syracuse Univ. (United States); Seungbo Shim, The Korean Research Institute of Standards and Science (Korea, Republic of); Elinor Irish, Univ. of Southampton (United Kingdom)

Mechanical quantum systems are being actively developed both for fundamental studies of quantum coherence and related topics at the macroscopic scale and to serve as elements in quantum information networks and quantum sensing applications. An important class of these systems includes electromechanical devices that incorporate superconducting qubits and circuitry into their design for the read-out and manipulation of nanomechanical elements. It is expected that such hybrid quantum systems should enable the production and measurement of a variety of non-classical states of nanostructures, making these systems a potentially versatile new element for quantum processing architectures and for testing decoherence in new limits. In this talk, I will give a brief overview of the burgeoning field of mechanical quantum systems and then highlight ongoing work in my group at Syracuse to integrate superconducting quantum devices with nanoelectromechanical systems.

9500-53, Session 8

Analog quantum computing (AQC) by revisiting the underlying physics

Paul J Werbos, Univ. of Memphis (United States)

Theorems have been proven that universal quantum computers based on qubits (Deutsch) and classical analog networks (Siegelmann) both have superTuring capabilities. It is a grand challenge to computer science to prove that the combination of the two, in analog (continuous variable) quantum computing, offers supersuperTuring capability, the best we can achieve. Computing with continuous spins is perhaps the most promising path to AQC for now. Two papers at SPIE2014 described unbreakable quantum codes based on continuous spins beyond what traditional qubits can achieve.

To make this real, we must first develop a realistic ability to model and predict the behavior of networks of spin gates which act in part as polarizers. Last year at SPIE (and arxiv) I proposed a "simple" triphoton experiment, in which three entangled photons are sent to linear polarizers set to angles theta a, theta b and theta c. The traditional assumption of "collapse of the wave function" yields a prediction for the coincidence detection rate, R3/R0(theta a, theta b, theta c) significantly different from the prediction of a new family of models based on classical Markov Random Fields (MRF) across space time, even though both yield the same correct prediction in the two-photon case. We cannot expect to predict systems of 100 entangled photons correctly if we cannot even predict three yet. The laboratory of Yanhua Shih is currently performing this experiment, as a first step to demonstrating a new technology to produce 100 entangled photons (in collaboration with Scully) and understanding larger systems. I have also developed continuous-time versions both of the MRF models and of "collapse of the wave function", as a step towards eliminating the need to assume metaphysical observers in general.

9500-54, Session 8

A CNOT gate within a glass chip

Warner A. Miller, Grigoriy Kreymerman, Florida Atlantic Univ. (United States); Paul M. Alsing, Air Force Research Lab. (United States)

Quantum gates and simple quantum algorithms can be designed utilizing the diffraction phenomena of a photon within a multiplexed holographic element. The quantum eigenstates we use are the photon's linear momentum (LM) as measured by the number of waves of tilt across the aperture. Two properties of quantum computing within the circuit model make this approach attractive. First, any conditional measurement can be commuted in time with any unitary quantum gate - the timeless nature of quantum computing. Second, photon entanglement can be encoded as a superposition state of a single photon in a higher-dimensional state space afforded by LM. We descriptor here our experimental results for construction a controlled NOT (CNOT) gate logic within a holographic medium, and present the quantum state tomography for this device. Our theoretical and numerical results indicate that OptiGrate's photo-thermal refractive (PTR) glass is an enabling technology. This work has been grounded on coupled-mode theory and numerical simulations, all with parameters consistent with PTR glass. We discuss the strengths (high efficiencies, robustness to environment) and limitations (scalability, crosstalk) of this technology. While not scalable, the utility and robustness of such optical elements for broader quantum information processing applications can be substantial.

9500-55, Session 8

Arbitrary error detection in a planar lattice of the surface code

Jerry M. Chow, IBM Thomas J. Watson Research Ctr. (United States)

Quantum error correction will be a necessary component towards realizing scalable quantum computers with physical qubits. Theoretically, it is possible to perform arbitrarily long computations so long as the error rate is below a threshold value. The two-dimensional surface code permits relatively high fault-tolerant thresholds at the ~1% level, and only requires a latticed network of qubits with nearest-neighbor interactions. Superconducting qubits have continued to steadily improve in coherence, gate, and readout fidelities, to become a leading candidate for implementation in to larger quantum networks. I will present recent experiments on systems of superconducting qubits arranged in a planar lattice, amenable to the surface code. Using a system of four qubits in a ring configuration we are able to detect an arbitrary single-qubit quantum error. The error detection protocol is based on the stabilizer formalism and protects a codeword encoded of an entangled two-qubit state via quantum non-demolition parity measurements, ZZ and XX, on two separate syndrome qubits. The -non-trivial- geometric arrangement of the qubits is essential to a surface code realization and is therefore extendable throughout the two-dimensional plane, encoding progressively larger logical Hilbert spaces towards a fully scaled fault-tolerant quantum computer.

Conference 9501: Satellite Data Compression, Communications, and Processing XI

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9501-1, Session 1

Future CNES high-resolution remote sensing missions: novel image compression approaches for on-board processing units

Roberto Camarero, Carole Thiebaut, Christophe Latry, Mathieu Albinet, Jean-Marc Delvit, Ctr. National d'Études Spatiales (France); Xavier Delaunay, THALES Services (France)

Current satellite on-board processing units usually follow a conservative scheme where simple operations are performed on the acquired pixels. Frequently, only image compression is done on-board, and in most cases, this compression is applied at a constant global bit-rate in order to simplify the storage and the acquisition and download schedules, as highly predictable data volumes are produced.

This constant or fixed rate paradigm represents in fact a huge constraint for image compressors. Firstly, it can be hard to obtain with classical entropy coders, because their variable-length codes naturally produce variable bit-rates. Secondly and more important, the same compression ratio must be applied to every image, without being able to take into account its content, its degree of interest or even its entropy.

Moreover, image-quality requirements are more and more difficult to satisfy because every final user has specific needs, and remote sensing imagery has become a crucial instrument in a large number of civil and military applications. Thus, as with fixed rate compression some image areas are better compressed than others, image-quality assessments must be established based on worst-case analysis, which provides very low compression ratios, even for state-of-the-art compressors.

CNES has been working for the last years in the characterization of image-quality requirements imposed by final users, in order to establish a relationship between the local image characteristics and the associated image quality requirements, or in other words, the tolerated compression losses.

As a result, the new functionalities included in the next generation of CNES image compressors will permit to accurately and locally adjust the compression ratio: the target quality level will be adapted for every area in the image taking into account not only its entropy but also its content and its degree of interest.

This new trend has required the adoption of variable rate compression, which has had a significant impact in other associated elements such as mission scheduling and storage. Other interesting on-board processing techniques have also been introduced in order to fully exploit the capacities of this new kind of compression.

9501-2, Session 1

Effects of compression on classification performance and discriminant information preservation in remotely sensed data

Chulhee Lee, Yonsei Univ. (Korea, Republic of); Jeoungyeol Baek, Yonsei Univ (Korea, Republic of); Sungwook Youn, Yonsei Univ. (Korea, Republic of)

Several compression methods have been used to reduce the data size of hyperspectral images. Among such compression methods, it has been shown that image compression based on the principal component analysis provides good compression efficiency for hyperspectral images. However, this compression method might fail to capture all the discriminant information of hyperspectral images since features which are important for classification may not be high in signal energy. In this paper, we investigate this problem and analyze potential discriminant information loss. Then, we explore several hybrid options, which can be used to preserve discriminant information, which is needed for classification, but may not be high in signal energy. In particular, we first encode hyperspectral images using an existing compression method. Then we generate residual images by subtracting reconstructed images from the original images. We also apply a feature extraction method to the original images, which produces a set of feature vectors. By applying these feature vectors to the residual images, we generate discriminant feature images which provide the discriminant information missed during the initial encoding process. Also, we investigate the effects of compression in remotely sensed data. In some cases, due to the nature of remotely sensed data, classification accuracy may increase at low bit rates. We examine this phenomenon and its implication. Experiments with AVIRIS data show that the proposed method can improve classification accuracy compared to other compression methods.

9501-3, Session 1

Hyperspectral image compression using an online learning method

Behcet U. Töreyin, Irem Ulku, Cankaya Univ. (Turkey)

A hyperspectral image compression method is proposed using an online dictionary learning approach. The online learning mechanism is aimed at utilizing least number of dictionary elements for each hyperspectral image under consideration. In order to meet this "sparsity constraint", basis pursuit algorithm is used.

In an earlier study on hyperspectral image compression, authors devised an online dictionary learning method formulated as a regularized least-squares based unconstrained optimization problem. Due to the formulation of the regularized problem, the linear combination of the dictionary elements obtained after learning process, do not have to perfectly match the hyperspectral image intensity values. Having said that, the earlier method yields comparable compression performance with that of the state-of-the-art methods in the literature.

In order to further improve the performance of the online dictionary learning based hyperspectral image compression method, a new formulation is proposed in this paper. Contrary to the earlier one, the proposed dictionary learning based compression scheme is re-formulated in such a way that, at the end of the learning process, the hyperspectral image values match with the linear combination of the dictionary elements. This new formulation and its corresponding solution strategy, which is known as basis pursuit algorithm, are widely used in the spectral unmixing of hyperspectral imagery. However, to the best of our knowledge, this is the first hyperspectral image compression study using an online dictionary learning approach based on basis pursuit algorithm.

Hyperspectral imagery from AVIRIS datasets are used for testing purposes. Effects of non-zero dictionary elements on the compression performance are analyzed. Results indicate that, the proposed online dictionary learning algorithm may be utilized for higher data rates, as it performs better in terms of PSNR values, as compared with the state-of-the-art predictive lossy compression schemes. It should be also noted that, a pre-analysis of the number of non-zero dictionary elements may improve the performance of the compression scheme.

9501-4, Session 1

A novel compression for hyperspectral images based on invariant set multi-wavelets

Yongjun Li, Yunsong Li, Xidian Univ. (China)

Hyperspectral images consist of a set of contiguous images bands collected by a hyperspectral sensor, and huge amounts of data of hyperspectral image shave become a great challenge to data storage and transmission, so the compression seems to be essential. In compression, wavelets have shown a good adaptability to a wide range of data, and being of reasonable complexity. Some wavelet-based compression algorithms have been successfully used for some hyperspectral space missions. A novel hyperspectral image compression scheme in the wavelet domain is proposed in this letter. Firstly, on the basis of the theory of invariant set multi-wavelets which is established by Micchelli and Xu, a biorthogonal multi-wavelets filter is designed in this paper, and it has many characteristics, such as symmetry, compact support and orthogonality. In this filter, the self-affine triangle domain is as support interval, and constant function is as scaling function. These properties can be used to well describe the image information. Secondly, the algorithms of decomposition and reconstruction of this filter and the test about the decomposition and reconstruction of hyperspectral image are given, the experiment result is analyzed. After a decomposition, 16 decomposition results which is called wavelet decomposition channel can be obtained. Each wavelet decomposition channel is decomposition information of the original image in one direction. The first channel in the upper left corner is a low frequency channel, the rest of the high frequency channel. The invariant set multi-wavelet compared with 9/7 wavelet and 5/3 wavelet, not only has the higher sparse, lower time complexity, no boundary distortion, and suitable for parallel processing. Experiments show that our proposed scheme is capable of providing high compression performance.

9501-5, Session 1

FPGA based JPEG-LS encoder for onboard real-time lossless image compression

Yakup Murat Mert, TÜB?TAK B?LGEM ?LTAREN (Turkey)

As the amount of the data increases for reconnaissance satellites with increasing resolution, data transmission and storage capabilities become insufficient. In this case, data compression ability is considered mandatory for efficient usage of the communication bandwidth, transmission power and storage capacity. However, data compression method should have low complexity for implementation ease as well as low power and weight budget. Besides, it should support high data rates for real-time compression and storage efficiency.

JPEG-LS Image compression standard defines image compression methods for continuous-tone gray-scale or multi component images for lossless and near lossless compression. Standard is based on LOCO-I (Low Complexity Lossless Compression for Images) algorithm. Its low complexity feature implies small hardware requirement and pixel by pixel prediction encoding results compression capability with very high throughput. JPEG-LS also simplifies the host system by eliminating the need for buffering sufficient amount of data to start compression as opposed to transform based compression methods. Despite to its simplicity and high rate, JPEG-LS offers very high lossless compression ratio. Consequently, its advantages on simplicity and compression performance make it suitable method for on-board real-time image compression.

JPEG-LS has straightforward algorithm composed of arithmetic operations and comparisons which makes it a good candidate for pipeline implementation. However, due to the variable update procedures of the algorithm, computed data in one pipeline stage should be forwarded to another stage to achieve full pipelined architecture. Otherwise, pipeline should be stalled for the same consecutive contexts to complete a variable update required for processing another one. Stalling the pipeline will reduce the encoding throughput as stalling time will become significant even for small size pictures. Without optimization, the data forwarding between pipeline stages leads to increase in delay and it has impact on the encoder performance as well. Some designs used multiple clock domains to handle the data forwarding scheme which means noticeable design complexity. Additional pipeline stages were also employed to reduce the delay stemmed from data-loop. However, this led to variable updates with out-of-date values, which implies a change on algorithm and impact on compression performance. An optimized solution for the data forwarding is based on the the products of the algorithm.As the prediction correction value, C[Q], is either incremented/decremented by 1 or remains same at the end of its update procedure, evaluating these 3 possible cases for error computation and selecting the proper result at the variable update stage significantly reduces the delay. This approach was adopted by many designs. On the other hand, only a few designs claimed to implement run mode and run interruption sample encoding and proposed optimization for those procedures.

In this study, an efficient field programmable gate array (FPGA) implementation of the JPEG-LS encoder for lossless image compression is introduced. Proposed encoder architecture comprises both regular mode and run mode with run interruption sample encoding procedures for full compliance with the ISO/ITU standard. Differently from former reported implementations, prediction error computation is optimized with pipeline data forwarding technique for minimum delay and complexity. Besides, procedures of the run-length encoding are realized using look-up tables without update latency. Synthesis results showed that our optimizations improved processing speed of the encoder noticeably while FPGA hardware footprint is significantly reduced compare to former JPEG-LS encoder designs.

9501-6, Session 2

Simplex volume analysis for finding endmembers in hyperspectral imagery

Hsiao-Chi Li, Univ. of Maryland, Baltimore County (United States); Meiping Song, Dalian Maritime Univ. (China); Chein-I Chang, Univ. of Maryland, Baltimore County (United States)

This paper explores the issue of simplex volume calculation from two different aspects, geometric structure and eigen-analysis. The geometric structure is derived from its simplex structure whose volume can be calculated by multiplying its base with its height. On the other hand, eigen-analysis takes advantage of the Cayley-Menger determinant to calculate the simplex volume. Experimental results show that geometric structure-based method yields the most reliable simplex volume.

9501-7, Session 2

Super-resolution imaging in remote sensing

Qiuhua Luo, Xiaopeng Shao, Lin Wang, Ligen Peng, Yi Wang, Xidian Univ. (China)

A new effective image super-resolution (SR) algorithm which is a hybrid of multiple frame Variational Bayesian (VB) reconstruction and single frame Dictionary Learning (DL) reconstruction method is developed to reconstruct a high resolution (HR) satellite image in this article. Firstly, employing a variational Bayesian analysis, the unknown high resolution image, the acquisition process, the motion parameters and the unknown model parameters are built together in a single mathematical model with a Bayesian formula, and then the distributions of all unknowns are jointly estimated. Without any parameter adjustment, a HR image is adaptively reconstructed from multiple frame low resolution (LR) images. Secondly, taking the above HR image as input, a higher resolution image can be rebuilt utilizing the statistical correlation between the HR and LR images which is obtained via the DL method. The VB method effectively uses non-redundant information between LR images to recover HR satellite images. Benefit from the dictionary training of magnanimity image, the DL algorithm is able to provide more high-frequency image details, which means this hybrid of VB and DL method combines the above advantages. The experiments show that this proposed algorithm can effectively increase the image resolution of remote sensing image by 0.5 at least comparing with low resolution image.

9501-8, Session 2

Hyperspectral image classification with a universal extreme learning machine

Qian Du, Mississippi State Univ. (United States); Wei Li, Beijing Univ. of Chemical Technology (China)

Extreme learning machine (ELM) is a neural network with only one hidden layer and one linear output layer. The weights between the input and the hidden layers are randomly assigned and the weights of the output layer are computed using a least squares method. Therefore, the computational cost is much lower than any other neural network based methods (including the popular support vector machine (SVM)). The major objective is to avoid parameter tuning while still being able to maintain satisfactory classification accuracy. The parameters in an ELM include: the size of random matrix (which is related to the number of hidden neurons), and the scaling factor of a binary sigmoid function in the hidden layer. Since each row of the random matrix is to linearly combine all the bands of an input sample pixel, the maximum size of the matrix is a square matrix (i.e, the number of hidden neurons equals the number of spectral bands) to make the hidden-layer-inputs non-singular. The scaling factor of the sigmoid function is critical, and the rule of thumb is that the maximum and minimum values of hidden-layer-outputs should be away from the extreme values (i.e., 1 and 0) in order to be distinguishable. The experimental results show that such a simple universal ELM outperforms the standard SVM, and offers similar performance as an ensemble ELMs but maintaining extremely low computational cost.

9501-9, Session 2

GSM-MR compression algorithm with two step sorting based on similarity analysis

Fei Cheng, Kai Liu, Jin Zhang, Wenwen Ding, Yunsong Li, Xidian Univ. (China)

Collecting reliable and accurate MR (Measure Report) data on time plays a vital role in the mobile communication network optimization. However, with the increment of the number of mobile users, network bandwidth cannot meet with mass transfer of MR. A high performance and high compression ratio GSM-MR compression algorithm is proposed to gain better transfer time. This algorithm utilizes two step sorting in order to reduce the distance between similar content, based on the analytic result about similarities of GSM-MR data sorting by different fields. Experimental results reveal that the algorithm does not only decrease compression consuming time, but also ascends compression ratio with the increment of the size of compression data.

9501-10, Session 3

Pesticide residue quantification analysis by hyperspectral imaging sensors

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Pesticide residue detection in agriculture crops is a challenging issue and is even more difficult to quantify pesticide residue resident in agriculture produces and fruits. This paper conducts a series of base-line experiments which are particularly designed for three specific pesticides commonly used in Taiwan. The materials used for experiments are single leaves of vegetable produces which are being contaminated by various amount of concentration of pesticides. Two sensors are used to collected data. One is Fourier Transform Infrared (FTIR) spectroscopy. The other is a hyperspectral sensor, called Geophysical & Environmental Research (GER) 2600 spectroradiometer which is a battery-operated field portable spectroradiometer with full real-time data acquisition from 350 nm to 2500 nm. In order to quantify data with different levels of pesticide residue concentration, several measures for spectral discrimination are developed. Mores specifically, new measures for calculating relative power between two sensors are particularly designed to be able to evaluate effectiveness of each of sensors in quantifying the used pesticide residues. The experimental results show that the GER is a better sensor than FTIR in the sense of pesticide residue quantification.

9501-11, Session 3

Adaptive sparse signal processing for discrimination of satellite-based radiofrequency (RF) recordings of lightning events

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Ongoing research at Los Alamos National Laboratory studies the Earth's radiofrequency (RF) background utilizing satellite-based RF observations of terrestrial lightning. The Fast On-orbit Recording of Transient Events (FORTE) satellite, launched in 1997, provided a rich RF lightning database. Application of modern pattern recognition techniques to this dataset may further lightning research in the scientific community, and potentially improve on-orbit processing and event discrimination capabilities for future satellite payloads. We extend sparse signal processing techniques to radiofrequency (RF) transient signals, and specifically focus on improved signature extraction using sparse representations in data-adaptive dictionaries. We present various processing options and classification results for on-board discharges, and discuss robustness and potential for capability development.

9501-12, Session 3

An automatic fractional coefficient setting method of FODPSO for hyperspectral image segmentation

Weiying Xie, Yunsong Li, Xidian Univ. (China)

In this paper, the spectrum has been already taken into consideration by integrating various types of band selection algorithms, firstly. We provide a short overview of the hyperspectral image to select an appropriate set of bands by combining supervised, semi-supervised and unsupervised band selection algorithms. Some approaches are not limited in regards to their spectral dimension, but are limited with respect to their spatial dimension owing to low spatial resolution. The addition of spatial information will be focused on improving the performance of hyperspectral image segmentation for later fusion or classification. Here, an automatic fractional

coefficient setting method of fractional-order Darwinian particle swarm optimization (FODPSO) is proposed for hyperspectral image segmentation to extend previous limitation. Many researchers have advocated that a large fractional coefficient should be in the exploration state while a small fractional coefficient should be in the exploitation, which does not mean the coefficient purely decrease with time. Due to such reasons, we propose an adaptive FODPSO by setting the fractional coefficient adaptively for the application of final hyperspectral image segmentation. In fact, the paper introduces an evolutionary factor to automatically control the fractional coefficient by using a sigmoid function. Therefore, fractional coefficient with large value will benefit the global search in the exploration state. Conversely, when the fractional coefficient has a small value, the exploitation state is detected. Hence, it can avoid optimization process get trapped into the local optima. Ultimately, the experimental segmentation results prove the validity and efficiency of our proposed automatic fractional coefficient setting method of FODPSO compared with traditional PSO, DPSO and FODPSO.

9501-13, Session 3

Optimizing the updated Goddard shortwave radiation weather research and forecasting (WRF) scheme for Intel many integrated core (MIC) architecture

Jarno Mielikainen, Bormin Huang, Hung-Lung A. Huang, Univ. of Wisconsin-Madison (United States)

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 updated Goddard shortwave radiation Weather Research and Forecasting (WRF) 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 co-processor 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 Xeon Phi will require using some novel optimization techniques. Those optimization techniques are discusses in this paper.

9501-14, Session 3

Progressive band processing of orthogonal subspace projection in hyperspectral imagery

Hsiao-Chi Li, Yao Li, Cheng Gao, Univ. of Maryland, Baltimore County (United States); Meiping Song, Dalian Maritime Univ. (China); Chein-I Chang, Univ. of Maryland, Baltimore County (United States)

Progressive band processing (PBP) processes data band by band according to the band sequential (BSQ) format used by hyperspectral imaging sensor. It can be implemented in real time in the sense that data processing can be performed whenever bands are available without waiting for data completely collected. This is particularly important for satellite communication when data download is limited by bandwidth and transmission. This paper presents a new concept of processing a well-known technique, orthogonal subspace projection (OSP) band by band, to be called PBP-OSP. Several benefits can be gained by PBP-OSP. One is band processing capability which can allow different receiving ends to process data whenever bands are available. Second, it enables users to identify significant bands during data processing. Third, unlike band selection which requires knowing the number of bands needed to be selected or band prioritization PBP-OSP can process arbitrary bands in real time with no need of such prior knowledge. Most importantly, PBP can locate and identify which bands are significant for data processing in a progressive manner. This progressive profile on OSP performance is the best advantage that PBP-OSP can offer and cannot be accomplished by any other OSP-like operator.

9501-15, Session 4

Orthogonal projection based fully constrained spectral unmixing

Meiping Song, Dalian Maritime Univ. (China); Hsiao-Chi Li, Yao Li, Cheng Gao, Chein-I Chang, Univ. of Maryland, Baltimore County (United States)

OSP has been used widely in detection and abundance estimation for about twenty years. But it can't apply nonnegative and sum-to-one constraints when being used as an abundance estimator. Fully constrained least square algorithm does this well, but its time cost increases greatly as the number of endmembers grows. There are some tries for unmixing spectral under fully constraints from different aspects recently. Here in this paper, a new fully constrained unmixing algorithm is prompted based on orthogonal projection process, where a nearest projected point is defined onto the simplex constructed by endmembers. It is much easier, and it is faster than FCLS with the mostly same unmixing results. It is also compared with other two constrained unmixing algorithms, which shows its effectiveness too.

9501-16, Session 4

Optical design for computing super-resolution imaging

Xiaopeng Shao, Jiaoyang Wang, Jie Xu, Xiaodong Chen, Xidian Univ. (China)

A novel optical design method is introduced for computing super-resolution (SR) imaging. Traditional optical design method is to optimize the merit function for good image quality. Computing SR imaging mainly uses single frame or video to reconstruct high resolution images and computing SR's constraint conditions mean that a kind of images is suitable for SR. So we design a novel optical design to acquire a sort of images for SR. The innovation is to combine the merit function of the optical design with the SR's constraint conditions together. Optical imaging system with low complexity and resolution is designed and the random-exposure coding pattern based on motion is made. In order to optimize the global performance, the trade-off between the optical design and the image processing is necessary to consider. The results show that although the Modulation Transfer Function (MTF) of the optical imaging systems is not best, it can provide image signals that are suitable for SR, consequently acquiring more details and higher resolution images. The novel optical design method can decrease data redundancy, remarkably improve the effective utilization of image signals, achieve cost reduction and simultaneously acquire SR images. This method is applicable for many areas, especially for the satellite-borne earth observation remote sensing imaging.

9501-17, Session 4

A multiple constrained signal subspace projection for target detection in hyperspectral images

Lena Chang, Yen-Ting Wu, National Taiwan Ocean Univ. (Taiwan); Yang-Lang Chang, National Taipei University of Technology, Taiwan. (Taiwan)

The hyperspectral images have been widely applied to target detection. Generally, the target signatures should be known a priori for filter-based detection methods. However, the uncertainty of target signatures caused by the influence of atmosphere interference or other random noise degrades

detection performance. Thus, developing a robust detection method is important in hyperspectral image analysis.

In the study, we propose a linearly constrained signal subspace projection (SSP) approach to target detection. Instead of using single constraint on target detection, we design an optimal filter with multiple constraints on desired targets by using SSP. The proposed SSP approach fully exploits the orthogonal property of two orthogonal subspaces: one denoted signal subspace containing desired and undesired/background targets; the other denoted noise subspace, which is orthogonal to signal subspace. By projecting the weights of the detection filter on the signal subspace, the proposed SSP can reduces some estimation errors in target signatures and alleviate the performance degradation caused by uncertainty of target signature. The SSP approach can detect desired targets, suppress undesired targets and minimize the interference effects. In experiments, we provide three methods in selecting multiple constraints of the desired target: K-means, principal eigenvectors and endmenber extracting techniques. Simulation results show that the proposed SSP with multiple constraints selected by K-means has better detection accuracy, fast convergence rate and large output SINR than other filter-based target detection methods. Furthermore, the proposed SSP with multiple constraints is a robust detection approach which could overcome the uncertainty of desired target signature in real image data.

9501-18, Session 4

Breast mass segmentation in digital mammography based on Pulse coupled neural network and Level set method

Weiying Xie, Xidian Univ. (China); Yide Ma, Lanzhou University (China); Yunsong Li, Xidian Univ. (China)

A novel approach to mammographic image segmentation, termed as PCNN-based level set algorithm, is presented in this paper. Just as its name implies, a method based on pulse coupled neural network (PCNN) in conjunction with the variational level set method for medical image segmentation. To date, little work has been done on detecting the initial zero level set contours based on PCNN algorithm for latterly level set evolution. When all the pixels of the input image are fired by PCNN, the small pixel value will be a much more refined segmentation. In mammographic image, the breast tumor presents big pixel value. Additionally, the mammographic image with predominantly dark region, so that we firstly obtain the negative of mammographic image with predominantly dark region except the breast tumor before all the pixels of an input image are fired by PCNN. Therefore, in here, PCNN algorithm is employed to achieve mammary-specific, initial mass contour detection. After that, the initial contours are all extracted. We define the extracted contours as the initial zero level set contours for automatic mass segmentation by variational level set in mammographic image analysis. What's more, a new proposed algorithm improves external energy of variational level set method in terms of mammographic images in low contrast. In accordance with the gray scale of mass region in mammographic image is higher than the region surrounded, so the Laplace operator is used to modify external energy, which could make the bright spot becoming much brighter than the surrounded pixels in the image. A preliminary evaluation of the proposed method performs on a known public database namely MIAS, rather than synthetic images. The experimental results demonstrate that our proposed approach can potentially obtain better masses detection results in terms of sensitivity and specificity. Ultimately, this algorithm could lead to increase both sensitivity and specificity of the physicians' interpretation of mammograms in clinical practice.

9501-19, Session 4

Parallel implementation of WRF double moment 5-class cloud microphysics scheme on multiple GPUs

Melin Huang, Bormin Huang, Hung-Lung A. Huang, Univ. of Wisconsin-Madison (United States)

The Weather Research and Forecast (WRF) Double Moment 5-class (WDM5) mixed ice microphysics scheme predicts the mixing ratio of hydrometeors and their number concentrations for warm rain species including clouds and rain. WDM5 can be computed in parallel in the horizontal domain using multi-core GPUs. In order to obtain a better GPU performance, we manually rewrite the original WDM5 Fortran module into a highly parallel CUDA C program. We explore the usage of coalesced memory access and asynchronous data transfer. Our GPU-based WDM5 module is scalable to run on multiple GPUs. We will report the computing performance of the GPU-based WDM5 scheme.

9501-20, Session 4

Richardson-Lucy deblurring for the star scene under a thinning motion path

Laili Su, Xiaopeng Shao, Lin Wang, Haixin Wang, Xidian Univ. (China); Yining Huang, Huawei Technologies Co. Ltd (China)

This paper puts emphasis on how to model and correct image blur that arises from a camera's ego motion while observing a distant star scene. Concerning the significance of accurate estimation of point spread function (PSF), a new method is employed to obtain blur kernel by thinning star motion path. In particular, how the blurred star image can be corrected to reconstruct the clear scene with a thinning motion blur model which describes the camera's path is presented. This thinning motion path to build blur kernel model is more effective at modeling the spatially motion blur introduced by camera's ego motion than conventional blind estimation of kernel-based PSF parameterization. To gain the reconstructed image, firstly, an improved thinning algorithm is used to obtain the star point trajectory, so as to extract the blur kernel of the motion-blurred star image. Then how motion blur model can be incorporated into the Richardson-Lucy (RL) deblurring algorithm, which reveals its overall effectiveness, is detailed. In addition, compared with the conventional estimated blur kernel, experimental results show that the proposed method of using thinning algorithm to get the motion blur kernel is of less complexity, higher efficiency and better accuracy, which contributes to better restoration of the motion-blurred star images.

9501-37, Session PThu

A Novel Super Resolution Camera Model

Xiaopeng Shao, Yi Wang, Jie Xu, Lin Wang, Fei Liu, Qiuhua Luo, Xiaodong Chen, Xidian Univ. (China); Xiangli Bi, School of Optoelectronics, Beijing Institute of Technology (China) and Science and Technology on Electro-Optical Information Security Control Laboratory (China)

A novel super-resolution camera model is proposed for the problem that the resolution of the images obtained by traditional cameras behave comparatively low, aiming to realize super-resolution to single image and video reconstruction. To achieve this function we put a certain driving device such as piezoelectric ceramics in the camera. By controlling the driving devices, a set of continuous low-resolution images can be obtained and stored instantaneity, which reflect the randomness of the displacements and the real-time performance of the storage very well. The low resolution image sequences have different redundant information and some particular priori

information, so it is possible to restore super-resolution image factually and effectively. The sample method is used to derive the reconstruction principle of super-resolution, which analyzes the possible improvement degree of the resolution in theory at the same time. The super-resolution algorithm based on dictionary learning is used to reconstruct single image and then the variational Bayesian algorithm is simulated to reconstruct the low resolution images with random displacements, which models the unknown high resolution image, motion parameters and unknown model parameters in one hierarchical Bayesian framework. Utilizing sub-pixel registration method, a super-resolution image of the scene can be reconstructed. The results of 16 images reconstruction show that this camera model can increase the image resolution to 2 times, obtaining images with higher resolution in now available hardware levels. However, this novel model also exist the problem of large amount of calculation and longtime of imaging.

9501-38, Session PThu

Research on IR thermal emission polarization characteristics of smooth surface material

Fei Liu, Xiaopeng Shao, Bin Xiangli, Lin Wang, Ying Gao, Xidian Univ. (China)

The IR thermal emission polarization characteristics model have been established by the physical mechanism of the infrared thermal emission and polarization of light, aiming at the problems existing in the long-wave infrared target detection field. As the key step, the thermal emission polarization theory of point source, a basement of the polarization studies, is analyzed through Kirchhoff's law, Snell theorem and Fresnel formula in detail. The influence factors of the object's infrared thermal emission polarization characteristics such as emission angle, complex refractive index and so on have been analyzed. In addition, the polarization characteristics model of the surface source has been built to calculate the degree of linear polarization for the smooth surface of different materials. The results show that different materials have their own polarization characteristics in a similar environment and the degree of linear polarization is changed with some influence factors. Moreover, a sensitivity analysis is presented to quantitatively describe the impacts of detection distance and the location of the target. In particularly, whatever the materials it is, the infinite surface source is not of the polarization characteristics. At the same time, the model also demonstrated that the polarization characteristics of a finite surface source vary with its locations.

9501-39, Session PThu

Simulation on polarization states of finite surface for infrared scenes

Ying Gao, Lin Wang, Xiaopeng Shao, Fei Liu, Xidian Univ. (China)

A simulation method for analyzing infrared polarization scenes has been proposed in order to study infrared spontaneous emission polarization deeply, since current infrared polarization devices can't show the polarization signature of infrared spontaneous emission for a target or a body well. A preliminary analysis on polarization characteristics of infrared spontaneous emission in the ideal case is carried out and also a corresponding ideal model is established through the Kirchhoff's law and the Fresnel theorem. Based on the newly built ideal model, a 3 dimensional (3D) scene modeling and simulation based on the OpenSceneGraph (OSG) rendering engine is utilized to obtain the polarization scene of infrared emission under ideal conditions. Through the corresponding software, different infrared scenes can be generated by adjusting the input parameters. By interacting with the scene, the infrared polarization images can be acquired readily, also a fact can be obviously confirmed that the degree of linear polarization for an object in the 3D scene varies with the many factors such as emission angle and complex refractive index. Moreover, large difference between two kinds of material such as metal and nonmetal in the polarization characteristics of infrared spontaneous emission at the same temperature can be easily discerned in the 3D scene. The 3D scene simulation and modeling in the ideal case provides a direct understanding on infrared polarization property, which is of great significance for the further study of infrared polarization characteristics in the situation of real scenes.

9501-40, Session PThu

Lightning Detection and Exposure Algorithms for Smartphones

Haixin Wang, Xiaopeng Shao, Lin Wang, Peng Gao, Laili Su, Xidian Univ. (China); Yining Huang, Huawei Technologies Co.Ltd (China)

This study focuses on the key theory of lightning detection and exposure and the experiments are conducted by building an experimental platform, containing CMOS (Complementary Metal Oxide Semiconductor)imaging sensor, photoflash?and module to generate the effects of lightning. Firstly, the algorithm based on differential operation between two adjacent frames was selected to remove the lightning background information and extract lighting signal, and the threshold detection algorithm was applied to achieve the purpose of precise detection of lightning. Secondly, an algorithm is proposed to obtain scene exposure value, which can automatically detect external illumination status. Then a look-up table could be built on the basis of the relationships between the exposure value and average image brightness. Based on the look-up table, the exposure values of two adjacent frames will be equal. The optimal exposure time can be determined by the optimal exposure value, so that rapid automatic exposure will be accomplished. Finally, based on a USB 3.0 industrial camera including a CMOS imaging sensor, a set of hardware test platform is established and experiments are carried out on this platform to verify the performances of the proposed algorithms. The algorithms can effectively and fast capture clear lightning pictures such as special nighttime scenes, which will provided beneficial supporting to the smart phone industry, since the current exposure methods in smart phones often lost capture or induce overexposed or underexposed pictures.

9501-41, Session PThu

Blind Image Noise Assessment Based On Local Phase Coherence

Lin Wang, Xiao Li, Xidian Univ. (China); Yanyun Zhang, Xidian University (China); Jiaobo Gao, Mingyin Jiao, Xi'an Institute of Applied Optics North Electro-optics Group Co., Ltd (China)

Remote Sensing Image can be degraded by a variety of causes during acquisition, transmission, compression, storage and reconstruction. Noise is one of the most important degradation factors. Quantifying its impact on the image may be useful for applications such as improving the acquisition system and thus the quality of the produced images. Objective IQA(Image Quality Measure) methods can be classified by whether a reference image, representing the original signal exists. In the case of remote sensing, the ideal un-degraded image is not available. NR (no-reference) method is required to blindly assess the image quality. In this paper, a new NR algorithm is proposed to quantify the image noise based on LPC (local phase coherence). This algorithm assumes that the input image is contaminated by additive zero mean Gaussian noise. To locate and estimate the noise in the degraded image, LPC, which states the consistent relationship in the phases of complex wavelet coefficient across scales in the vicinity of sharp image features, is carried out on both the noisy image and the denoised image which is obtained by using a low-pass filter on the noisy image to suppress the noise. After comparing the differences between the two LPC images, the impact of the noise on image quality can be quantified by a simple calculation model. Experiment results show that the proposed

algorithm correlates well with subjective quality evaluations and has high estimation accuracy especially for the Gaussian noise-infected images.

9501-42, Session PThu

Research of ghost imaging with spatial light modulator

Xiaopeng Shao, Yang Zhang, Xue'en Wang, Lin Wang, Xidian Univ. (China)

Ghost imaging, also named quantum imaging,is a special optical technology which has incomparable advantages in term of anti-interference, non-locality, breakthrough in a number of limit laws of classical optics. In recent years,much research has been conducted on the ghost imaging which is based on two-photon quantum states and classic hot lights. However, the high cost of the experiments and the influences of the limited experimental conditions on experimental data result difficulties in achieving desired outcomes.In this paper, by using classical phase-sensitive light source, we simplified the two optical paths in conventional ghost imaging experiments, and achieved single-pixel detector ghost imaging. Based on the in-depth analysis of ghost imaging's physical nature and imaging mechanism's derivation, this paper will give a brief introduction of the structure, and phase modulation principle of spatial light modulator will be discussed. By using spatial light modulator to achieve artificial light phase modulation, the information of optical field distribution can be obtained in advance. With the help of relevant software, the photocurrent detected by single-pixel bucket detector can be computed associatedly with the optical field distribution, to achieve a clear image of the object. In the end, the paper will discuss the quantum nature of ghost imaging with different light sources,and present the future prospect of ghost imaging in remote sensing and medicine.

9501-43, Session PThu

Design of a wide-field imaging optical system with super-resolution reconstruction

Xiaopeng Shao, Jie Xu, Jiaoyang Wang, Xiaodong Chen, Xidian Univ. (China); Rui Gong, School of Physics and Optoelectronic Engineering, Xidian University (China); Xiangli Bi, School of Optoelectronics, Beijing Institute of Technology (China) and Science and Technology on Electro-Optical Information Security Control Laboratory (China)

The need for a portable image acquiring system has become as strong as the extension of digital imaging technology, for this, a new mono-centric and wide-field optical design is proposed. In recent few years, some high-resolution and wide-field imaging systems have been raised already, their sizes are comparatively too large to be carried conveniently while with which fairly clear and wide field of view (FOV) images could be easily obtained. With ZEMAX, a new optical design is emulated by scaling the structure of current wide-field optical systems and increasing some micro lens array, the size of which is about 10mm*10mm*20mm while the structure of which includes a two-glass mono-centric lens, micro lens array (the lenses in the array can be different), a specific detector and some other devices. Micro lens array is used to make the image plane from curve to almost flat. This hardware is small enough to apply to helmets and computers and the FOV of which is wide enough. Verified by a series of merit function, this optical design is found to have a just acceptable imaging resolution and the computational imaging method is applied to this system to acquire a higher imaging resolution. From each micro lens a series of low resolution images are obtained and in this system a high-resolution image can be retrieved from multiple low-resolution images with super-resolution reconstruction method. Compared from the size and the imaging resolution, this new optical design is much smaller and has a high imaging resolution.

9501-51, Session PThu

Airborne experiment results for spaceborne atmospheric synchronous correction system

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The Image quality of optical remote sensing satellites is affected by the atmosphere, thus the images need to be corrected. Due to the spatial and temporal variability of atmospheric conditions, correction by using synchronous atmospheric parameters can effectively improve the remote sensing image quality. For this reason, a small light spaceborne instrument, the atmospheric synchronous correction device(airborne prototype), is developed by AIOFM of CAS(Anhui Institute of Optics and Fine Mechanics of Chinese Academy of Sciences). With this instrument, of which the detection mode is time synchronization and spatial coverage, the atmospheric parameters consistent with the images to be corrected in time and space can be obtained, and then the correction is achieved by radiative transfer model. To verify the technical process and treatment effect of spaceborne atmospheric correction system, the first airborne experiment is designed and completed. The experiment is implemented by the "satellite-aircraft-ground" synchronous measurment method. A high resolution(0.4 m) camera and the atmospheric correction device are equipped on the aircraft, which photograph the ground with the satellite over the top simultaneously. And aerosol optical depth (AOD) and columnar water vapor (CWV) in the imagery area are also acquired, which are used for the atmospheric correction for satellite and aerial images. Experimental results show that using the AOD and CWV of imagery area inversed by the data obtained by the device to correct satellite and aerial images, can improve image clarity and contrast by more than 30%, and increase MTF by more than 1 times, which means atmospheric correction for satellite images by using the data of spaceborne atmospheric synchronous correction device is correct and efficient.

9501-21, Session 5

Finding endmember classes in hyperspectral imagery

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Endmember finding has received considerable interest in hyperspectral imaging. In reality an endmember may not actually exist due to spectral variability caused by many unknown factors such as noise, interfering effects, lack of calibration. In this case a real endmember may appear as its variant rather than a pure signature. To resolve this dilemma a general approach is to find endmember classes which contain real endmembers and their spectral variations. Despite that endmember variability issue has been studied extensively finding endmember classes or bundles seems easily said than done. This paper develops a new approach to finding endmember classes, called algorithm for finding endmember classes (AFEC). It consists of two components. In its first component an unsupervised algorithm is implemented to find an initial set of potential endmember candidates and then followed up by the second component which develops an algorithm to refine endmember classes iteratively, called iterative algorithm for refining endmember classes (IAREC). In order to demonstrate its utility and effectiveness synthetic and real image experiments are conducted and its performance is also evaluated and compared to several common approaches reported in the literature. The results show that our proposed approach perform the best among all the test algorithms.

9501-22, Session 5

Skeleton-based action recognition using multiple sequence alignment

Wenwen Ding, Kai Liu, Fei Cheng, Jin Zhang, YunSong Li, Xidian Univ. (China)

Human action recognition and analysis is an active research topic in computer vision for many years. This paper presents a method to represent human actions based on trajectories consisting of 3D joint positions. This method first decompose action into a sequence of meaningful atomic actions (actionlets), and then label actionlets with English alphabets according to the Davies-Bouldin index value. Therefore, an action can be represented using a sequence of actionlet symbols, which will preserve the temporal order of occurrence of each of the actionlets. Finally, we employ sequence comparison to classify multiple actions through using string matching algorithms (Needleman-Wunsch). The effectiveness of the proposed method is evaluated on datasets captured by commodity depth cameras. Experiments of the proposed method on three challenging 3D action datasets show promising results.

9501-23, Session 5

Support vector machine with adaptive composite kernel for hyperspectral image classification

Wei Li, Beijing Univ. of Chemical Technology (China); Qian Du, Mississippi State Univ. (United States)

With the improvement of spatial resolution of hyperspectral imagery, it is more reasonable to include spatial information in classification. It has been demonstrated in the literature that the resulting spectral-spatial classification outperforms the traditional hyperspectral image classification with spectral information only. Among many spectral-spatial classifiers, support vector machine with composite kernel (SVM-CK) can provide superior performance, with one kernel for spectral information and the other for spatial information. In SVM-CK, the spatial information is retrieved by spatial averaging of pixels in a local neighborhood, say, a 3-by-3 or 5-by-5 window, and used in classifying the center pixel. Obviously, not all the pixels in such a local neighborhood may belong to the same class. Thus, we propose an adaptive composite kernel, named SVM-ACK, to improve the performance. In SVM-ACK, an image segmentation step is conducted first, and then only the pixels potentially belonging to the same class within the window will be actually averaged for spatial feature extraction. The experimental result demonstrates that the proposed SVM-ACK can obviously outperform SVM-CK.

9501-24, Session 5

Construction of WRF Stony Brook University 5-class scheme on Intel many integrated cores (MICs)

Melin Huang, Bormin Huang, Hung-Lung A. Huang, Univ. of Wisconsin-Madison (United States)

The Weather Research and Forecasting (WRF) model is mesoscale numerical weather prediction system. It is designed to serve the needs of both operational forecasting and atmospheric research ranging from meters to thousands of kilometers. Microphysics process plays an important role in weather and climate prediction, which provides atmospheric heat and moisture tendencies. Several microphysics schemes are available within the WRF, with different numbers of simulated hydrometeor classes and algorithms for estimating their size, fall speeds, distributions, and densities. Stony Brook University 5-class (SBU5) is one of microphysics schemes with riming intensity predicted to account for the mixed-phase processes. In this paper, we construct a parallel implementation of SBU5 scheme on Intel many integrated cores (MICs). The computing performance of MIC-based SBU5 scheme will be reported.

9501-25, Session 5

Semi-supervised hyperspectral unmixing approach based nonnegative matrix factorization

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Hyperpsectral unmxing is a hot topic in hyperspectral data processing.

For many cases, partial ground-objects in the image can be easily known [1], for example, the tree always exists in most of natural scenes. While, it is easy to obtain the spectrum of known objects from the spectral library or filed measurement. Generally, more accurate results should be obtained using prior information [2]. Nonnegative matrix factorization can naturally satisfy the nonnegative constraint in HU [3]. Therefore, we try to construct the semi-supervised HU approach based NMF in this paper.

The paper tries to make full use of the prior information in 2 aspects: 1) the prior information is imbedded in original NMF model, in which the endmember matrix A is divided into the known endmembers A1 and the estimated endmembers A2. During the iterative procedure, only A2 needs to be updated. Correspondingly, a new update rule should be derived. Under the improvement, the non-convex problem of original NMF can be partially relieved. But this improvement doesn't consider the relation between the prior endmembers and the unknown endmembers. In other words, it doesn't support enough prior information for estimating the unknown information. Therefore, another improvement is proposed. 2) The prior information is used to construct constrained function based on orthogonal subspace theory [4]. Specifically, the constrained function is constructed by projecting the unknown endmembers to the orthogonal subspace of known endmembers. The larger the function value is, the larger the distance between estimated endmembers and orthogonal subspace spanned by known endmembers. Actually, it fits for the property of real the endmembers.

We will evaluate the algorithm using 2 synthetic datasets and 2 real datasets comparing with classical unmixing methods: SISAL [5], VCA [6] and MVCNMF [7].

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9501-26, Session 5

Virtual Dimensionality Analysis for Hyperspectral Imagery

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This paper investigates and explores insights into these two scenarios, signal strength and signal energy used for binary hypothesis testing problems to estimate VD. It further develops their probability distributions for hypothesis testing to estimate VD. It turns that the values of VD obtained by these two scenarios are quite different.

9501-27, Session 6

A new detection algorithm for microcalcification clusters in mammographic screening

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A novel approach for microcalcification clusters detection is proposed. At the first time, we make a short analysis of mammographic images with microcalcification lesions to confirm these lesions have much greater gray values than normal regions. After summarizing the specific feature of microcalcification clusters in mammographic screening, we make more focus on preprocessing step including eliminating the background, image enhancement and eliminating the pectoral muscle. In detail, Chan-Vese Model is used for eliminating background. Then, we do the application of combining morphology method and edge detection method. After the AND operation and Sobel filter, we use Hough Transform, it can be seen that the result have outperformed for eliminating the pectoral muscle which is approximately the gray of microcalcification. Additionally, the enhancement step is achieved by morphology. We make effort on mammographic image preprocessing to achieve lower computational complexity. As well known, it is difficult to robustly achieve mammograms analysis due to low contrast between normal and lesion tissues, there are also much noise in such images. After a serious preprocessing algorithm, a method based on blob detection is performed to microcalcification clusters according their specific features. The proposed algorithm has employed Laplace operator to improve Difference of Gaussians (DoG) function in terms of low contrast images. A preliminary evaluation of the proposed method performs on a known public database namely MIAS, rather than synthetic images. The comparison experiments and Cohen's kappa coefficients all demonstrate that our proposed approach can potentially obtain better microcalcification clusters detection results in terms of accuracy, sensitivity and specificity.

9501-28, Session 6

Adaptive nearest feature space approach to remote sensing image classification

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In this paper a novel technique based on nearest feature space (NFS), known as adaptive nearest feature space (ANFS), is proposed for supervised remote sensing image classification. The nearest feature space (NFS) has been proven to be efficient for remote sensing image classification in recent years. NFS feature space is constructed by three nearest labeled samples of the same class, which can better handle the variations of the samples than the well-known nearest feature line (NFL) as it can provide more information to virtually enlarge the training samples set. Although NFS can perform well for classification, in some instances, it decreases the efficiency when samples of different classes are not far apart or even overlapped. Due to the different neighborhood structures of overlapping training labels, the traditional NFS can't perform well for classification of remote sensing images. In response, ANFS is proposed to overcome this problem. It combines and adopts two methods, NFS and incenter-based nearest feature space (INFS) which makes use of the incircle of three labeled samples to form a INFS, to achieve the best classification accuracy. In ANFS, a fitting preprocessing of NFS is presented to determine what the best fix models (NFS/INFS) is for the three nearest labeled samples of the same classes. Furthermore, in order to speed up the computation performance of the ANFS classifier, this paper proposes a parallel computing version of ANFS. It makes use of the modern graphics processing unit (GPU) architecture with NVIDIA's compute unified device architecture (CUDA) technology to improve the computational speed of ANFS. Experimental results demonstrate the proposed ANFS approach is suitable for land cover classification in earth remote sensing. It can achieve the better performance than NFS classifier when the class sample distribution overlaps. A better computational speedup can also be gained through the parallel computing of GPU.

9501-29, Session 6

Progressive band processing of pixel purity index for finding endmembers in hyperspectral imagery

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Pixel purity index (PPI) is a very popular endmember finding algorithm due to its availability in ENVI software developed by AIG. This paper introduces a new concept of executing PPI band-by-band in a progressive manner, called progressive band processing of PPI (PBP-PPI) which allows users to process PPI band by band without waiting for full bands of data information completed. In order for PPI to be carried out by progression the PPI used by PBP-PPI is somewhat different from the commonly used PPI in the sense that PPI must be performed on a band acquisition basis according to the band sequential (BSQ) format. To accomplish this goal PPI should be capable of calculating PPI counts sample by sample for any given set of skewers and in the mean time PPI can also process samples band by band. The proposed PBP-PPI is developed to meet these needs. One great benefit resulting from PBP-PPI which PPI does not have is the progressive profiles of PPI counts of data samples as more bands are included for data processing. As a result, data analysts can use progressive changes in PPI counts to identify significant bands for finding endmembers.

9501-30, Session 6

Collaborative representation for hyperspectral image classification

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Sparse representation has been a popular classifier for hyperspectral image classification, where a pixel under test is represented by labeled samples with a sparseness constraint and it is assigned to the class whose labeled samples produce the minimum representation residual. Such a classifier does not have the traditional training and testing procedures, but can generate classification accuracy comparable to that of the classical support vector machine. Deviated from the popularity of sparsity, we propose to impose a collaborative constraint so that the representation coefficients tend to have a minimum L2 norm. Such a collaborative representation based classifier has a closed form solution, making it much more efficient than the sparse representation based classifier and support vector machine. Its classification performance is even better after imposing a similarity-

based regularization in representation. In this paper, we further discuss the performance of the regularized collaborative representation based classifier by utilizing spatial information, including joint collaborative model and weighted joint collaborative model, which can further improve its classification accuracy.

9501-31, Session 7

A vegetation classification method based on optimization of feature band set using hyperspectral remote sensing data

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There are two major problems of vegetation classification using hyperspectral remote sensing (HRS) data. Classification results using only spectral information can hardly meet the application requirements, as the classes become more and more sophisticated. And the application of classification results is also limited due to the salt and pepper noise. Therefore a classification strategy based on construction and optimization of vegetation feature band set (FBS) is proposed. Besides the spectral and texture features of original image, 30 spectral indices which are sensitive to the biological parameters of vegetation are added into FBS in order to improve the separability between different classes. A spectral dimension optimization algorithm of FBS based on class-pair separability (CPS) is also proposed. A spatial dimension optimization algorithm of FBS based on neighborhood pixels' spectral angle distance (NPSAD) is proposed so that detailed information can be kept during the image smoothing process. The validation result based on airborne HRS image shows that the proposed method can significantly improve the classification accuracy so that the widespread application prospects in identification of crop species, monitoring of invasive species and precision agriculture are expectable.

9501-32, Session 7

Accurate estimation of motion blur parameters in noisy remote sensing image

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The relative motion between remote sensing satellite sensor and objects is one of the most common reasons for remote sensing image degradation. It seriously weaken image data interpretation and information extraction. In practice, point spread function (PSF) of a blurred image should be estimated firstly for image restoration. Identifying motion blur direction and length accurately is very crucial for estimating PSF and restoring the blurred image with precision. In general, the regular light-and-dark stripes in the motion blur image spectrum can be employed to obtain the parameters by using Radon transform. However, serious noise existing in real remote sensing images often causes the light-and-dark stripes in the spectrum unobvious. The motion blur parameters would be difficult to calculate and the error of the result relatively big. In some case, the estimated values even show great deviation from the actual ones. In this paper, an improved motion blur parameter identification method to the noisy remote sensing image is proposed to solve this problem. The spectrum characteristic of noisy remote sensing image is analyzed firstly. An interactive image segmentation method based on graph theory is adopted to effectively extract the edge of the light center in the spectrum. The motion blur direction is estimated by applying Radon transform on the segmentation result. In order to reduce random error, a method based on whole column statistics is used during calculating the blur length. Finally, Lucy-Richardson algorithm is applied to restore the remote sensing images of the moon after estimating the blur parameters. The experimental results verify the effectiveness and robustness of our algorithm.

9501-33, Session 7

Further optimization of dynamics code of the advanced research weather research and forecasting (ARW) model for Intel Xeon Phi

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The Weather Research and Forecast (WRF) model is the most widely used community weather forecast and research model in the world. There are two distinct varieties of WRF. The Advanced Research WRF (ARW) is an experimental, advanced research version featuring very high resolution. The WRF Nonhydrostatic Mesoscale Model (WRF-NMM) has been designed for forecasting operations. WRF consists of dynamics code and several physics modules. The ARW core is based on an Eulerian solver for the fully compressible nonhydrostatic equations. In the paper, we will use Intel Intel Many Integrated Core (MIC) architecture to increase the performance of the ARW dynamics. It is the most time consuming part of the ARW. So, any speed increase of dynamics will be also reflected of the overall speed of the ARW. We will describe the challenges we met during the development of a high-speed dynamics code subroutine for MIC architecture. Furthermore, lessons learned from the code optimization process will be discussed.

9501-34, Session 8

A super-resolution algorithm for degraded satellite image

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An effective algorithm for super resolution (SR) reconstruction of remote sensing image is proposed in this article, which first estimates point spread function (PSF) of the degraded image from a knife edge and then reconstructs a high resolution (HR) image from a set of low resolution (LR) images by utilizing the above estimated PSF with Bayesian super resolution (BSR) method. In this process, a knife edge, even irregular in shape, from which a high precision PSF can be obtained, is automatically picked up from many candidate edges according to the neighborhood features of the image. Concerning that accurate estimation of sub-pixel motion between the LR images would significantly affect the quality of the reconstructed HR image, the BSR method which is robust to errors in the estimation of the motion parameters is employed in this algorithm, because it can simultaneously reconstruct the HR image and estimate the motion information of LR images. To suppress the artifacts and noise of the HR image, the total variation (TV) method is applied in reconstruction as well. The experiments show that the proposed approach can provide useful high-frequency details for LR remote sensing images, which verifies its effectiveness in SR reconstruction. Compared with low resolution image, the spatial resolution and the modulation transfer function (MTF) of the reconstructed HR image could be at least increased by 0.4 and 0.2, respectively.

9501-35, Session 8

Hyperspectral vital sign signal analysis for medical data

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The linear logistic regression model (LLRM) is a probabilistic statistical classification model which has been widely used for predicting the outcome of a categorical dependent variable (i.e., a class label) based on one or more predictor variables (features) via the logistic sigmoid function. Unfortunately, it suffers from two major issues, (1) the data are generally skewed and (2) training data are required to estimate parameters in LLRM. This paper develops a complete new technology, called Hyperspectral Vital Sign Signal Analysis (HyVSSA) from a hyperspectral imaging perspective. A hyperspectral image is generally acquired by hundreds contiguous spectral bands, each of which is an optical sensor specified by a particular wavelength. As a result, a hyperspectral data vector is a column vector whose components are signals produced by hundreds spectral bands. Now if we consider each sensor which produces a particular spectral band as a medical device to produce a patient's particular vital sign signal of interest as the way signals acquired by a spectral band, a patient with vital sign signals (VSSs) measured by various medical devices can be then represented by a hyperspectral data vector with each component specified by a particular VSS as a spectral band and thus, the number of hyperspectral data vectors to be processed becomes the number of patients to be considered. In light of this interpretation a revolutionized concept is developed, which translates medical data to hyperspectral data in such a way that hyperspectral technology is readily applied to medical data analysis. Consequently, new competing techniques and methods can be further derived from hyperspecral technology as an alternative to LLRM to be used in analyzing medical data. This paper explores this new technology and its applications to medical data which are very generally skewed, for example, prediction of outcomes of blood transfusion where abnormal data is only very small portion of the entire data set and LLRM may not be effective or inapplicable.

9501-36, Session 8

Dehazing method through polarimetric imaging and multi-scale analysis

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An approach utilizing polarimetric imaging and multi-scale analysis has been developed to solve one problem that haze weather weakens the interpretation of remote sensing as the result of poor visibility and short detection range. On the one hand, the polarization effects of the airlight and the object radiance in the imaging procedure has been considered, then the inversion of haze-free image is able to be got through establishing polarization hazy imaging model. On the other hand, one fact that objects and haze possess different frequency distribution properties has been emphasized. So multi-scale analysis through wavelet transform has been employed to make it possible for low frequency components that haze presents and high frequency coefficients that image details or edges occupy are processed separately. Firstly, according to the measure of the polarization feather by Stokes parameters, three linear polarimetric images (0°, 45°, and 90°) have been taken on haze weather, then the best polarized image and the worst one can be synthesized. Secondly, those two polarized images contaminated by haze have been decomposed into different spatial layers with multi-scale analysis, and the low frequency images have been processed via a polarization dehazing algorithm while high frequency components manipulated with a nonlinear transform. Then the ultimate haze-free image can be reconstructed. Experimental indices such as effective detection range, image contrast, PSNR and image definition verify that the dehazing method proposed in this study can strongly promote image visibility and increase detection distance through haze for imaging warning and remote sensing systems.

9501-44, Session 8

Error correction capability aware BCH implementation for NAND flash memories in Earth observation satellites

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In this paper, a parallel FPGA architecture implementing BCH error correction for NAND flash memories in storage modules of Earth observation satellites (EOS) is presented. In order to satisfy the error correction requirements of NAND flash memories the designed module is capable of correcting 4 erroneous bits in code words (CW) of 4148 bits using shortened BCH (4148, 4096) algorithm. Besides the standard BCH encoding and decoding procedure a code selection module is added to the architecture to guess whether or not the CW has more than 4 errors. If more than 4 errors occurs in the CW the architecture understands that the CW is uncorrectable and does not try to change any bits which will most probably inject more errors to the CW. The design is implemented on a XC7VX485T FPGA from Virtex 7 series of Xilinx and with a 300 MHz system clock, it is capable of encoding and decoding information at 4,78GBits/sec.

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